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Music Perception of Cochlear Implant Recipients: Impacts of Stimuli Characteristics, Device Technology, & Individual Differences

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Learner Objectives

• The learner will be able to describe those structural features of music that are most to least effectively transmitted through a cochlear implant.

• The learner will be able to describe how cochlear implants mediate perceptual accuracy and enjoyment of the most salient features of music.

• The learner will be able to describe those listener differences (e.g., auditory history, age when implanted, residual hearing, cognitive processing, personality characteristics) that are associated with more satisfactory music perception and appreciation.
Iowa Cochlear Implant
Clinical Research Team

Grant 2 P50 DC00242 from the NIDCD, NIH; grant RR00059 from the General Clinical Research Centers Program NCRR; Grant R01DC012082 - 01A1 from NIH-NIDCD; DOD Grant 11352158.

Music and CI Benefit:
Relevance to Audiologists

1. CI recipients will be exposed to music regularly in everyday life.

• How can we help our patients with realistic expectations?
• What can be done to improve music enjoyment in everyday life?
Music and CIs

2. Music, a spectrally complex signal, challenges the technical limits of the CI.

- Are there technical advances that could enhance perception and enjoyment?
- Could enhancement of music carry over to spectrally complex aspects of speech?

Links:
Music and Speech Perception

- Talker identification
- Tonal languages
- Vocal inflection
- Background noise
Music and CIs

3. CI users differ considerably in how they utilize signal processing.

• Can we help CI users to be strategic in navigating a complex auditory world?
• How can individual user differences inform patient counseling?

1. CI users will be exposed to music most everyday
• “People spend more money on music than on prescription drugs.” (D. Huron, 2001)

Music and Mood Regulation

• Change arousal level
  – Increase energy
  – Promote relaxation

• Achieve a positive mood

(e.g., Goethem & Sloboda, 2011; Sloboda, 2010).
Music—an acoustic scrapbook

Sound Samples

• A series of sound samples is played during this section of the presentation
2. Music is Challenge to CI Signal Processing!

Listening Environment +
Musical Features

CI Technical
Features

Individual
Listener

Meaningful
Music?

Signal Processing and Perception

**Speech**
- Requires as few as 4 bands of coarse spectral cues (Shannon, Zeng, Kamath, Wygonski, & Ekelid)
- Adult CI users: Mean=80% word recognition in a **quiet** with 3-6 months CI use (Blake Wilson, 2000).

**Music**
- > 32 functional channels, better encoding of the fine structure information are required for transmitting melody and timbre (Smith, Delgutte, & Oxenham, 2002).
- Limited improvement from everyday use
Narrow frequency range

Degraded representation of the fine, complex elements of music

What components of music are best? Worst?

(Looi, Gfeller & Driscoll, 2012, Limb & Roy, 2014)
Putting the components together

Name that Tune
Technical Considerations

Technical Issues

• Limitations
  – Disruption in place pitch mechanisms
  – Disruption in rate pitch mechanisms
  – Dynamic range compression

Perceptual Outcomes

• Hearing preservation; bimodal hearing

Auditory Scene Analysis

Rhythm  Pitch  Timbre  Dynamics

(Looi, Gfeller & Driscoll, 2012; Limb & Roy, 2014)
Music and CI Advances

Hybrid vs. LE: Pitch Ranking
Hybrid vs. LE: Melody Recognition

Simple Melody Recognition

Complex Melody Recognition

(Gfeller et al., 2006, 2007, 2010)

When music competes with conversation
Speech Recognition in Background Music: SNR

![Graph showing SNR threshold for different musical excerpt types and listening environments.]

The listening environment can detract or enhance music

![Diagram illustrating listening environment + musical features leading to CI technical features and an individual listener, with a question about meaningful music?]

continued
Listening Environment: Avoid Noisy Rooms, Loud Music

- Noisy room: 92% response
- Echo in room: 90% response
- Loud music: 66% response

Better Listening Environment, Signal Input

- Specific coding strategy: 28% response, 38% no experience
- Optimal concert seating: 55% response, 29% no experience
- Direct audio input: 18% response, 75% no experience
- Headphones: 18% response, 78% no experience
- Quality recording: 76% response, 11% no experience

n = 179
3. CI users differ considerably in how they utilize signal processing.

BAD!

GOOD!

Individual Characteristics

Listening Environment + Musical Features → CI Technical Features → Individual Listener → Meaningful Music?
Variability Among CI Users

“Music sounds like a cage full of squawking parrots!”

“I can hear the music, but it doesn’t make any sense.”

“I try to listen to music daily. It satisfies a deep hunger of mine.”

“Music opens up ways to enjoy and cope with life.”

Listening Habits:
Adult CI Users

[Histogram showing listening habits before and after implantation]
Diversity of CI Users: Influential Factors for Music

- Social, familial values
- Situation-specific motivation, attitude
- Enduring personality traits
  - Openness, extraversion, conscientiousness, agreeableness
- Music-driven experience-based plasticity
  - Informal
  - Formal
    - Protocols, materials, frequency, length, age when initiated
- Auditory development (electrical/acoustic stimulation)
- Mental representation of musical structure
- Plasticity
- Cognitive, behavioral, social maturation
- Precision, efficiency of CI-mediated hearing
- Efficiency, flexibility of related cognitive processes

(Gfeller et al., 2008; 2010; Looi, Gfeller & Driscoll, 2012)
Context and Visual Cues

Name that tune-----with cues
Helpful Accommodations?
Familiarity, Accessible Cues

<table>
<thead>
<tr>
<th>Accommodation</th>
<th>Percent Response</th>
</tr>
</thead>
<tbody>
<tr>
<td>familiar music</td>
<td>88</td>
</tr>
<tr>
<td>knowing song title</td>
<td>78</td>
</tr>
<tr>
<td>watch performer</td>
<td>81</td>
</tr>
</tbody>
</table>

n=179

Listening to Familiar Music

• “It does help . . if I know what it’s supposed to sound like. For example, the ‘Star Spangled Banner’ started to sound fairly normal about a week into the Olympics, but I think this is my brain filling in the missing pieces.”
Training or Focused Practice

- Music training can improve timbre recognition, timbre appraisal, and pitch perception of adult listeners.

(Driscoll, et al., 2009; Driscoll, 2012; Fu and Galvin, 2007; Galvin, Fu & Nogaki, 2007; Galvin et al., 2009; Gfeller et al., 2000a, b, 2002; Loebach & Pisoni, 2008; Loebach, Pisoni, & Svirsky, 2009)

Results of Training
Behavioral Outcomes

Complex Song Recognition

Gfeller et al., 2001
Many factors influence CI benefit

Optimizing Music Enjoyment

- Realistic, individualized expectations
  - Taking advantage of residual hearing
  - Focusing on accessible features of music,
  - Taking control over environmental factors
- Compensate with visual, contextual cues
- Optimize through training/practice
Bilateral Cochlear Implants
Ruth Litovsky
University of Wisconsin
Madison, WI USA

Learner Outcomes

1) Describe the potential benefits of bilateral cochlear implants
2) Summarize ways to behaviorally test for cochlear implant benefit
3) Explain the limitations of bilateral cochlear implant
4) Consider the importance of listening effort and cognitive load in auditory processing
Importance of hearing and learning in natural listening environments

Bilateral cochlear implantation ~20 years; continued need to improve outcomes

Health insurance coverage varies for adults and children, across countries
→ Sequential vs. Simultaneous?
→ How low should speech scores be?

Minimize social isolation

Behavioral measures, e.g. speech understanding in noise and localization

Reduction of listening effort or cognitive load

Growing trend: Implant in both ears (bilateral)

Families vary in decision making

Age not a factor as much as lifestyle & neural health
Binaural cues for sound localization on the horizontal plane
Sound reaches the near ear first → interaural time difference (ITD)

Two binaural cues for sound localization on the horizontal plane
Sound reaches the near ear with greater intensity → interaural level difference (ILD) → Monaural head shadow
In normal hearing listeners: exquisite sensitivity to ITDs at low frequency

Low Frequency: ITD sensitivity

In normal hearing listeners: exquisite sensitivity to ILDs at high frequency

High Frequency: good ILD sensitivity
In normal hearing listeners: sensitivity to ITDs in envelopes of high-frequency sounds

High Frequency: good sensitivity to ITDs in amplitude modulated tones (Envelope ITDs)

In Cochlear Implants: Fixed/high rate of stimulation, with slowly varying “envelope” (ENV) in each ear. **ITDs in envelopes** are possibly a good cue for spatial hearing
Behavioral Measures of Bilateral Benefits

Sound Localization

Ability of the auditory system to use spatial cues that need for us to integrate inputs from the two ears

Studies use loudspeakers that are arranged in a room (usually front), and patients are asked to report *where* a sound is heard

Behavioral testing for sound localization
Behavioral Measures of Bilateral Benefits

Speech Intelligibility

- In Quiet: Redundant information from R and L ears
- In Noise: Redundant information;
- Use of spatial cues to segregate speech and noise when they are from different locations

Other?
Quality of life, orientation;
Listening effort

In Adults: many studies documented benefits for speech understanding in noise with Bi-CI vs. Unilateral-CIs:

Despite improved performance with Bi-CIs, there remains a gap in performance relative to normal-hearing listeners

Agrawal and Litovsky, in prep
The cocktail party effect

Effects of adding a second ear

- Binaural Summation: Improvement of speech intelligibility when using two ears vs. one ear

One ear (Unilateral)  
- △ Target (speech)  
- ★ Masker (speech or noise)

Two ears (Bilateral)  
- △ Target (speech)  
- ★ Masker (speech or noise)
Effects of adding a second ear

- When the 'noise' is far from closed ear, listening can be difficult and SNR in good ear is challenging

<table>
<thead>
<tr>
<th>One ear (Unilateral)</th>
<th>Two ears (Bilateral)</th>
</tr>
</thead>
<tbody>
<tr>
<td>![Diagram 1]</td>
<td>![Diagram 2]</td>
</tr>
</tbody>
</table>

△ Target (speech)
★ Masker (speech or noise)

Effects of adding a second ear

- When the 'noise' is near the closed ear, benefit of monaural 'head shadow'

<table>
<thead>
<tr>
<th>One ear (Unilateral)</th>
<th>Two ears (Bilateral)</th>
</tr>
</thead>
<tbody>
<tr>
<td>![Diagram 3]</td>
<td>![Diagram 4]</td>
</tr>
</tbody>
</table>

△ Target (speech)
★ Masker (speech or noise)
Spatial Release from Masking

- Improvement of speech intelligibility when the target is spatially separated or *perceived* to be spatially separated from the interferer(s)
- Reduction in masking through spatial separation

- In children: Often measured with both CI’s on (natural)
- In adults: Can turn off one CI and look at benefit of two vs. one

Spatial Release from Masking (children)

- Improvement of speech intelligibility when the target is spatially separated or *perceived* to be spatially separated from the interferer(s)
- Reduction in masking through spatial separation

Co-located

Asymmetrically separated

Symmetrically separated
BICI users do not show binaural interaction effects.

- Bypass microphones
- Introduce directional cues with HRTFs
- Speech Stimuli
- Multi-channel stimulation
- Binaural cues available with single DSP processor, but individual electrode pairs no synched

Study in adults:

![Graph showing Spatial Release from Masking (dB) for Normal Hearing and Bilateral CI.](image)

Loizou, Hu, Litovsky (2009), JASA

Turning the task into a game for children ages 4 and older: 4AFC with spondees (within the child’s vocabulary)
Possible reasons for small improvement with spatial cues

1. Poor access to binaural cues
2. Poor ability to perceive and use cues
3. Not enough experience with bilateral CIs from a young age?

Misurelli and Litovsky, 2012; 2015
Summary of Spatial Release from Masking

- Adults show SRM; however, there is little or no evidence that effects are due to binaural processing. Monaural cues (head shadow) are clearly involved.
- Children show SRM; however, performance is variable. Some children show little or no SRM. Overall SRM is smaller than in age-matched peers.
- Except... in toddlers who received bilateral CIs at a very young age.
Summary of Spatial Release from Masking

- Limitations in Bilateral Cochlear Implants
  - Lack of binaural synchronization
  - Poor signal processing for representing ITDs
- Also need to consider
  - Neural Pathology

Behavioral Measures of Bilateral Benefits

Sound Localization

**IN CHILDREN**

Studies use loudspeakers that are arranged in a room (usually front), and patients are asked to report *where* a sound is heard.
Improved sound localization bilateral CIs vs. single CI; however, not as good as with normal hearing

Root Mean Square Error (RMS)

<table>
<thead>
<tr>
<th>One cochlear implant</th>
<th>Two cochlear implants</th>
<th>Normal hearing</th>
</tr>
</thead>
<tbody>
<tr>
<td>50-80°</td>
<td>15-30°</td>
<td>5-10°</td>
</tr>
</tbody>
</table>

Jones, Kan and Litovsky (2014)

In Adults: many studies documented benefits for sound localization in quiet with Bi-CIs vs. Unilateral-CIs:

1. Despite improved performance with Bi-CIs, there remains a gap in performance relative to normal-hearing listeners
2. Note: The two cochlear implants are not synchronized, but patients still see a benefit compared to 1 CI

Agrawal and Litovsky, in prep
Children: sound localization and effect of experience with bilateral CIs

Root Mean Square Error (RMS)

<table>
<thead>
<tr>
<th>Bilateral CIs within 1 year of activation</th>
<th>Bilateral CIs with 3-4 years experience</th>
<th>Normal hearing</th>
</tr>
</thead>
<tbody>
<tr>
<td>20-50°</td>
<td>15-35°</td>
<td>6-12°</td>
</tr>
</tbody>
</table>

Zheng, Godar and Litovsky (2015)

Localization in children with BiCIs

1) Unable to identify sound source locations (N=12)

Zheng, Godar & Litovsky; Plos One (2015)
Longitudinal Free-field measures

**Best Performer:**
- Longest exposure to bilateral Cis
- Acoustic hearing early in life

Statistical spatial independence between all possible pairs of response groups

Improvement in localization mostly in front (N=18)

3-4 years of additional experience: 1 year of additional experience

ILDs are poor in lateral angles (beyond 50 deg)
**What about localization in toddlers with BiCIs?**

**Test with ‘Reaching for sound’**

- Child only sees 2 holes in curtain:
  - +/- 60
  - +/-45
  - +/-30
  - +/-15

**RESULTS:**

All toddlers with BiCIs can *discriminate* angles as small as 15° when using both CIs.

Performance is either poor or they are unable to do the task with a single CI.

---

**Summary of Sound Localization**

- Adults are able to localize better with two than with one CI.
  - However, this is primarily in quiet; when listening in noise, they show large errors, at a much better SNR than NH listeners.
- Children localize with two CIs better than with one CI.
  - Children show improvement with experience, in particular for sound sources in front.
  - However, none of the children perform as well as normal hearing peers.
Summary of Sound Localization

• Limitations in Bilateral Cochlear Implants
  – Lack of binaural synchronization
  – Poor signal processing for representing ITDs
• Also need to consider
  – Neural Pathology

Limiting performance: Independently operating speech processors minimize/remove binaural cues
Other factors that limit performance

Lack of Stimulation AND:
Stimulation rate too high to not capture ITDs

Neural pathway degradation

Difference in the insertion of electrodes between ears

Difference in spread of excitation in R & L ears

What are the next steps?

- **Understand** the sources of limitation on performance
- **Design processors** that overcome the limitations
- **Study** performance in children in order to know which binaural cues should be preserved

**continued**
Approaches to restoring binaural inputs:
Bypass the microphones / processors
(to date only with Nucleus – Cochlear BiCl users)

Direct stimulation
- Small number of electrodes
- Precise control over stimulus reaching each electrode
- Excellent binaural cues

Research to date with adults and children shows that:
- ITDs highly “vulnerable” to deprivation.
- ILDs are highly “recoverable” after long-term deafness
- In adults and children

Litovsky et al. 2010; 2012; Laback et al. 2015
Listening to patient reports: “it’s easier with two ears than one” *improvement not always seen in %correct scores*

Objective measures of **listening effort / cognitive load** using an eye tracker → quantify pupil dilation

Pupil dilation also related to arousal state (attend to environment; flight/fright; controlled by norepinephrine)

PROCEDURE:
Listen to & repeat sentences while fixating on a monitor
Measuring:
“real time” processing

Work from our lab on use of pupil dilation
Winn et al. (2014, Ear Hearing)
Winn and Litovsky (2015, JASA)
Here: data from 2 new studies

Measuring listening effort / cognitive load using eye tracking: Effect of spectral resolution in speech

Winne, Edwards, Litovsky (Ear Hearing, 2015)
Measuring listening effort / cognitive load using eye tracking: Effect of spectral resolution in speech

Bilateral cochlear implant subjects (N=12)

Winn, Edwards, Litovsky (Ear Hearing, 2015)

Winn, Litovsky (in progress)
Bilateral cochlear implant subjects (N=12)

Winn, Litovsky (in progress)
Bilateral cochlear implant subjects (N=12)

- Bilateral listening mode produces reduced listening effort compared to either ear alone
- Often, patient’s subjective report re: which ear is ‘better’ or ‘worse’ is consistent with the amount of listening effort in each ear alone

Summary of Listening Effort

- Adults with normal hearing – tested using degraded speech – show that even when they have high %correct for speech understanding, pupil dilation is high for degraded conditions.
- Adults with bilateral CIs tested with either ear alone, or bilaterally, show that listening effort is reduced with bilateral compared to either ear alone.
Binaural Hearing and Speech Lab & collaborators

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Cochlear Implantation: Medical Surgical Issues

Debara L. Tucci, M.D.

Professor of Surgery
Division of Head and Neck Surgery &
Communication Sciences
Director, Cochlear Implant Program

23rd Annual Appalachian Spring Conference
June 10, 2016

Learning Objectives

After this presentation, participants will be able to:

1. List the potential surgical complications of cochlear implantation

2. List the surgical and electrode array options available for cochlear implant candidates who have cochlear ossification

3. Describe the overall risk of vestibular function loss (based on caloric tests) associated with cochlear implantation
Hearing Impairment Worldwide

- 278 million people worldwide have moderate to profound losses in both ears (WHO, 2005)
- Majority in developing countries - lack of preventative care such as vaccines, pre- and perinatal care; estimated that 50% of hearing loss is preventable
- Incidence of congenital hearing loss is 2-4/1000 births in developed countries, 6/1000 in developing, with 718,000 born annually (of 120 million total) with significant hearing problem

Outline

- Medical evaluation and considerations
- Imaging studies
- Device selection
- Pre-implantation vaccinations
- Surgical procedure
- Surgical complications
- Follow up
Cochlear Implant: Medical Evaluation

- Otologic assessment – candidate for treatment of SNHL?
- Otologic assessment – past surgical procedures or conditions that may influence surgical approach or device selection?
- Imaging – to assess for cochlear abnormalities, retrocochlear pathology
- Prevention of complications: meningitis vaccination
- General assessment – candidacy for general anesthetic and surgical procedure
- Assessment of cognitive and mental health

Cochlear Implant: Pre-CI Assessment

- Assess prior history of ear disease – particularly ear infections and history of eustachian tube dysfunction
- Surgical approach through facial recess requires normal middle ear space and lack of any infection
- Problems:
  - perforation, cholesteatoma; infection
  - atelectasis of tympanic membrane with contracted middle ear space
- Solutions:
  - choose other ear for CI?
  - repair TM prior to CI
  - canal wall down approach with EAC closure
**Cochlear Implant: Medical Evaluation**
- Is CI the most appropriate treatment?

- Review history of hearing loss
- Fluctuation? Bilateral SNHL?
  - hypothyroidism; syphilis; autoimmune HL
- Sudden SNHL – sensitive to steroids?
- Far advanced otosclerosis?
  - history of progressive mixed hearing loss
  - early features of otosclerosis
  - may benefit from stapedotomy and hearing aid
- Pushing boundaries of candidacy – view patient as a whole – ability to use amplification, condition of opposite ear

---

**Case Study: WL, current age 26**

- Initially seen 2013 with history of recent loss of hearing in right ear, better hearing ear
- Also history of chronic ETD, chronic infections as child; S/P tube placement, tympanoplasty right
- 2007: developed sudden SNHL left ear
  - oral steroid with good response
- Work up: MRI, hydrocephalus; shunt placed
- Later in 2007: developed sudden SNHL right ear
  (previously normal hearing); oral prednisone with recovery
- Continued development of sudden SNHL bilaterally, with partial recovery following steroids
Case Study: WL, further history

- Hearing aid use left ear
- Continued intermittent otitis externa left; making hearing aid use difficult
- Progressive hearing loss right ear
- Family history of otosclerosis (mother and maternal relative)

Case Study: WL, Clinical Course, 2013

- Treated with oral prednisone with response
- Diagnosis: Autoimmune SNHL, with steroid dependence
  - noted improvement on 60 mg/day, followed by hearing deterioration when dropped dose to 40mg/d
- Failure to improve hearing further in right ear despite high dose oral prednisone and intratympanic steroids
- Referral to rheumatology for assessment of other autoimmune disease – work up negative
- Wearing bilateral amplification
Case Study: WL, Clinical Course

- Audiograms – subsequent slides show fluctuation of hearing in the right ear (better ear)

8/26/13
Case Study: WL, Clinical Course, 2015

- July 2015 = seen for first time since 2013 with report of malfunction of left ear hearing aid
- Audio now shows worsened hearing in left ear with 12% speech discrimination
- Right ear with severe SNHL and excellent SDS
- Not a conventional CI candidate due to relatively good hearing in the right ear (aidable)
- However, has significant fluctuation of hearing in the right ear, and has required oral and ITS treatment of fluctuating right ear SNHL; difficulty working due to hearing handicap, even with hearing aids
- Candidate for left ear CI
- Left ear CI performed on 5/26/16

7/27/15
Outline

• Medical evaluation and considerations

• Imaging studies
  • Device selection
  • Pre-implantation vaccinations
  • Surgical procedure
  • Surgical complications
  • Follow up

Preoperative Evaluation:
Temporal Bone CT

- Cochlear anatomy
- Cochlear patency
- Mastoid anatomy
Preoperative Evaluation: MRI

- Assess cochlear patency, anatomy
- Rule out vestibular schwannoma, other CNS abnormality
- MRI generally contraindicated post CI

Outline

- Medical evaluation and considerations
- Imaging studies
- **Device selection**
  - Pre-implantation vaccinations
  - Surgical procedure
  - Surgical complications
- Follow up
Device Selection: Electrode design

- Modiolar electrodes
- Mid-scalar electrodes
- Lateral wall electrodes

Companies have more than one type of electrode to offer, and many variations available

Only examples are shown

Modiolar Electrode: Cochlear Corporation Nucleus Contour

- Positions the stimulating electrode contacts close to neural elements
- Goals: reduce power consumption and increase stimulation selectivity
MidScalar Electrode

- Designed to avoid trauma to cochlear structures
- Capable of conserving cochlear function for hearing preservation

Advanced Bionics

Lateral Wall Electrode

- Designed to avoid trauma to cochlear structures
- Capable of conserving cochlear function for hearing preservation

Med El
FLEX Tip Technology

**The softest, most flexible electrode arrays**

- Thin FLEX tip due to single vs. double contacts
- Soft FLEX tip due to reduced number of wires
- Wave-shaped wires for maximum flexibility
- Minimal dimensions contribute to atraumaticity
- Contact spacing for best channel separation

---

**Electrode Array Comparison:**
MED-EL, Cochlear, and Advanced Bionics Cochlear Implants
Controversy over electrode length – the case for long electrode

- Access to cochlear apex
  - Improved cochlear coverage
  - Improved pitch matching across frequencies
  - Enhanced low frequency pitch perception, fine structure
  - Improves perception of music, tonal languages and ‘naturalness’ of speech

- Despite length, argue that preservation of structure is possible with longer electrodes

- Controversy: speech perception vs. conservation of cochlear structure

Controversy over electrode length – long electrodes not associated with better speech perception

- Longitudinal multicenter study De Seta et al, 2016
- 19 patients simultaneous bilaterally implanted by experienced CI surgeons
- 1-year and 5-year results
- Results:
  - Depth of insertion not associated with better hearing
  - Advocate for use of cochlear measurements to guide electrode choice

continued
Special considerations for electrode selection: Cochlear malformation

- Preoperative imaging important
- Common cavity – precurved (modiolar) electrode may be advantageous
- Hypoplastic cochlea – compressed array
- Mondini malformation – conventional array

Special considerations for electrode selection: Cochlear ossification

- Cochlear ossification involves basal turn, s. tympani preferentially
- Approaches to implantation:
  - Drill out with implantation of basal turn only (compressed array)
  - Implantation of scala vestibuli (extend cochleostomy 1-2 mm superiorly)
  - Split electrode array (basal and middle turns)
  - Radical cochleostomy (open trough extends around modiolus)
Pre-Implant Vaccinations

- Recognized early that patients with cochlear malformations at increased risk of meningitis with CI, from entry of bacteria from middle ear through cochleostomy

- In early 2000’s apparent that many patients not previously thought to be at risk for meningitis after CI were affected – CI positioner allowed route for bacteria through cochleostomy
Pre-Implant Vaccinations

- Centers for Disease Control and Prevention (CDC) Advisory Committee on Immunization Practices has issued recommendations for vaccinations prior to CI; these differ for adults and children.

- Two vaccinations required, according to specific schedule:
  - PCV13: 13-valent pneumococcal conjugate vaccine (Prevnar)
  - PPSV23: 23-valent pneumococcal polysaccharide vaccine (Pneumovax)

Outline

- Medical evaluation and considerations
- Imaging studies
- Device selection
- Pre-implantation vaccinations

Surgical procedure

- Surgical complications
- Follow up
Surgical Procedure

- Small postauricular incision
- Drill well for receiver stimulator
- Mastoidectomy
- Facial recess approach to cochlear promontory - open between facial nerve and tympanic membrane
- Identify round window
- Copious irrigation to clear bone dust
- Open RW and insert electrode by gently advancing into scala tympani
- Stabilize internal device with permanent suture

Postauricular incision
Surgical Procedure

- Facial nerve
- Chorda tympani nerve
- Facial recess

Surgical Procedure

- Mastoidectomy
- Facial recess
- Cochleostomy
Surgical Procedure

- Mastoidectomy
- Facial recess open
- Well drilled
- Device secured
- Cochleostomy
- Electrode inserted
HiFocus 1j electrode insertion

Place the HF 1j insertion tube at the cochleostomy toward the basal turn of the scala tympani.

Direct insertion tube slot superiorly toward the modiolar (or inner) wall.

Hearing/Structure Preservation Surgery

- **Goal** is atraumatic electrode insertion into scala tympani, to preserve cochlear structure and integrity – advance slowly; stop when resistance
- Most studies show that insertion through round window is optimal, but good results are also reported with a cochleostomy (opening anterior/ inferior to RW)
- **Principles**: steroids (various applications), clean field (no bone dust), small opening in RW membrane, slow insertion of electrode
- Principles important for both hybrid implants and conventional implants
Structure Preservation Surgery – the future

- Preservation of structure and integrity of cochlea does not preclude access to regenerative therapies in the future (no therapies that can restore structural damage)
- Customize electrode choice/length with cochlear measurements obtained via preoperative imaging
- Combination of cochlear implant with drug delivery to cochlea

Outline

- Medical evaluation and considerations
- Imaging studies
- Device selection
- Pre-implantation vaccinations
- Surgical procedure
- Surgical complications
- Follow up
Surgical Risks and Complications

- Risks of Anesthesia
- Infection – meningitis, wound infection
- Bleeding – risks increased if severe ossification
- Facial nerve injury – especially with cochlear malformations
- Tinnitus; activation of CI generally reduces - rationale for CI for SSD with tinnitus
- Dizziness – about 50% but likely temporary
- Implant failure (10 year warranty)
- Flap thickness over magnet

Outline

- Medical evaluation and considerations
- Imaging studies
- Device selection
- Pre-implantation vaccinations
- Surgical procedure
- Surgical complications
- Follow up
Post op and Follow up

- All patients receive 10 days of antibiotics
- Return 10-12 days postop for wound inspection (optional)
- Programming with Audiologist – 4-6 weeks postop
- Return to see me in 3 months after activation; then at least annually
- Follow up audiograms if candidate for second ear implant

Case Study: S.G.

- Presents to Durham VA 10/14 after care at Seattle VA
- Bilateral Meniere’s Disease
  - Left vestibular nerve section
  - Right endolymphatic sac surgery (unreported)
  - Episodic vertigo
  - Other related history unclear/poorly documented
- S/P Baha right; equipment failure
- Otosclerosis S/P bilateral stapedotomies
Case Study: S.G.

- **Audiogram 10/14**
  - Right: Severe to profound mixed HL; 100% SDS
  - Left: Profound SNHL; CNT SDS

Case Study: S.G.

- Presents 8/15 with following complaints:
  - Decreased function of right Baha
  - Increased vertigo (spontaneous and positional) and increased dysequilibrium
  - Daily falls (also lower extremity issues)

- Vestibular testing: bilateral hypofunction
- Audiogram right – profound mixed HL; 0% SDS
- Right intratympanic steroid injection – no change
Case Study: S.G.

- Cochlear implant evaluation – candidate for CI right ear
- Continued vertigo – consider ELSD same time
- Baha no longer useful/needed – remove abutment at time of CI surgery
- Imaging studies – normal cochlear structures

Case Study: S.G.; preop counseling

- Patient noted to be involved with ‘deaf’ community – documented patient acceptance
- Dizziness with bilateral vestibular hypofunction – implant surgery not expected to affect balance function
- Meniere’s disease – patient had already had ELSD on right
- Implanted right ear on 5/25/16; excellent NRT
- Med El Synchrony CI – allows 3T MRI (joint imaging)
Vestibular consequences of cochlear implantation

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June 10, 2016
Appalachian Spring Conference

Learning Objectives

• List the risk factors for potential vestibular dysfunction related to cochlear implant surgery
• Describe the incidence of complaints of imbalance of older adults (>60 years) in comparison to younger cochlear implant recipients
• Describe the vestibular tests that are most likely to reflect impairment post implant surgery
Questions:

• What are the effects of cochlear implantation on the physiology of the vestibular system (vestibular testing)?
• What are the effects of cochlear implantation on balance function (patient perception)?
• Is vestibular dysfunction more likely with certain surgical techniques or electrodes/implants?
• How can vestibular effects of CI be minimized?
• Should vestibular testing be done prior to cochlear implantation?

Talk Outline

• Vestibular tests – what are the components of a vestibular assessment and what information does each component provide (brief overview)?
• What are the effects of CI on vestibular test results?
• What are the effects of CI on patient reported balance function?
• Should vestibular testing be done prior to CI? Of so:
  – Which patients?
  – What tests?
Vestibular Assessments – brief overview

- VNG/ENG
- Rotational Chair
- Vestibular Evoked Myogenic Potential (cVEMP; oVEMP)
- Head Impulse Test (HIT)
- Platform Posturography
- Patient assessment of function

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Vestibular Assessments – brief overview

- VNG/ENG
  - VNG: Video camera monitors eye movements (can track torsional movements);  
  - ENG: electrodes around eyes monitor eye movements  
  - Oculomotor testing  
  - Vestibular assessment: Caloric testing, assesses horizontal canal function  
    - Unilateral weakness  
    - Bilateral weakness (confirm on rotational chair)  
  - Positional testing (Dix-Hallpike; assess for BPPV; calorics typically normal)

- Rotational Chair
- Vestibular Evoked Myogenic Potential (cVEMP; oVEMP)
- HIT
- Platform Posturography
- Patient assessment of function
Vestibular Assessments – brief overview

• VNG/ENG
• Rotational Chair – Sinusoidal Harmonic Acceleration (SHA)
  – Identifies extent of bilateral weakness
  – Data not ear-specific (combine with VNG)
  – Determines degree of vestibular compensation and integrity of compensatory pathways
• Vestibular Evoked Myogenic Potential (cVEMP; oVEMP)
• HIT
• Platform Posturography
• Patient assessment of function

CONTINUED
Vestibular Assessments – brief overview

- VNG/ENG
- Rotational Chair
- Vestibular Evoked Myogenic Potential (cVEMP; oVEMP)
- HIT – Head Impulse test
  - Rapid movement of patient’s head to left and right while focused on visual target
  - Covers wider range of ‘real world frequencies of stimulation (3-5 Hz), in contrast to caloric and rotational chair stim
  - Decreased VOR gain or compensatory saccades abnormal
  - Only objective test of superior and posterior canal function
  - Can be done in vertical and horizontal plane
  - vHIT – video recording
- Platform Posturography
- Patient assessment of function

Vestibular Assessments – brief overview

- VNG/ENG
- Rotational Chair
- Vestibular Evoked Myogenic Potential (cVEMP; oVEMP)
- HIT
- Platform Posturography – Computerized Dynamic Posturography (CDP)
  - Functional assessment, not site-of-lesion testing
  - Objective assessment – fall risk
  - Isolates inputs from vestibular, somatosensory and visual systems
  - Should be consistent with patient’s report of balance function
  - Inconsistent responses may indicate malingering
- Patient assessment of function
Vestibular Assessments – brief overview

• VNG/ENG
• Rotational Chair
• Vestibular Evoked Myogenic Potential (cVEMP; oVEMP)
• HIT
• Platform Posturography – functional assessment
• **Patient assessment of function**
  – Dizziness Handicap Inventory (DHI) – most widely used; validated; measures handicap or quality of life
  • 25 questions about the emotional, functional and physical impact of unsteadiness
  • High internal consistency; translated into 14 languages
  • Considered gold standard assessment
  – Other measures of vertigo frequency, severity

Effects of Cochlear Implantation on Vestibular Function

• Complex analysis – more than half of patients report dizziness *prior* to CI
• May depend on disease process causing hearing loss
• Suggestion that post CI dizziness may be more common in patients over age 60
• Unknown mechanisms of vestibular damage
• Anatomically may expect saccular damage, due to close association with cochlea; VEMP testing

CONTINUED™
Effects of Cochlear Implantation on Vestibular Function: possible mechanisms

- Electrode insertion trauma
- Intraoperative loss of perilymph
- Foreign body reaction or labyrinthitis
- Post-operative perilymph fistula
- Endolymphatic hydrops
- Electrical vestibular stimulation by the implant
- BPPV

- First 4 also associated with post CI loss of residual hearing

Effects of Cochlear Implantation on Vestibular Function: Test Findings

- Systematic review and meta-analysis by Abouzayd et al, 2016
- Original studies with detailed pre and post CI assessment
- Focus on: Calorics, cVEMP, HIT
- Found poor correlation between objective tests and subjective symptoms
- No single test achieved sensitivity better than 50%
Effect of Cochlear Implantation on Vestibular Function: Summary of Impairments

- Abouzayd et al, 2016
- Percentage impairment vs. post-operative delay
- Size of circle indicates number of patients

Effects of Cochlear Implantation on Vestibular Function

- Timing of assessment
  - Important to note for comparison between studies
  - Strong tendency for vestibular function to improve with time after CI
  - Recovery may result from recovery of vestibular sense organs after surgical trauma, or central compensation
  - Physical recovery – mechanisms and whether recovery occurs is poorly understood
Effects of Cochlear Implantation on Vestibular Function: Conclusions of Systematic Analysis

- **VNG/ENG/Calorics:**
  - Least effective test with only 21% sensitivity
  - Most frequently performed
  - Variable protocols (air vs. water; various temperature, durations, definition of asymmetry)
  - Site of stimulation is lateral canal ampulla; further from implant insertion than saccule.
  - One study showed impaired calorics is always associated with loss of measureable c-VEMP
  - Caloric test stimulates lateral ampulla at lower frequency than in daily life; may not be sensitive enough to detect impairment to physiologically important stimuli
  - **Conclude that probably not useful post CI**
    - Also, study by Patki et al. (next slide)

Effects of Cochlear Implantation on Vestibular Function: Patki et al study

- **Hypothesis:** Caloric irrigation results are correlated with temporal bone anatomy
- **Method:** Performed retrospective analysis of caloric irrigation results and temporal bone anatomy as assessed by analysis of CT scan (bone vs. air space, and distance to lateral semicircular canal);
  - subjects did not have vestibular pathology
Effects of Cochlear Implantation on Vestibular Function: Patki et al study

- Findings:
  - After mastoid surgery, the anatomy of the temporal bone is greatly altered
  - Bone is primary heat conductor to vestibular organs; air is a heat sink
  - Regression analysis shows decreased vestibular response to warm irrigation after mastoidectomy

- Conclusion: results of post-surgical vestibular caloric testing may be of limited utility, and results may not be directly comparable with pre-surgical findings
- Although calorics may be helpful pre-CI to define unilateral weakness, post-CI findings will be limited by test-related factors

Effects of Cochlear Implantation on Vestibular Function

- cVEMP:
  - Most frequently impaired, at >60% of patients at one month post CI
  - Correlates with fact that closest to cochlear electrode and most frequent vestibular sense organ damaged histologically after CI
  - Sensitivity 32% (compared with caloric sensitivity of 21%), NS
  - Relative to other measures is rarely done (5 studies)
  - Studies variable despite reporting clarity: response ‘present’ or ‘absent’
  - Variability in testing could explain inconsistency in study results:
    - Variation in tone of SCM
    - Variation in stimulus used (bone vs. air conduction); B/C thought best
    - Absolute response (present/absent) may not account for partially functioning saccule
Effects of Cochlear Implantation on Vestibular Function

• HIT:
  – Least frequently done so not a lot of data
  – Variable technique
  – May be useful in future to test all three SCCs due to close proximity between RW and posterior canal ampulla
  – Theoretically may explain dizziness in patients with normal calorics and cVEMPs

• Subjective assessment
  – Varied in studies from simple query to use of DHI
  – DHI
    • Results complex, as up to 58% of patients suffer from dizziness pre-CI
    • Best to study variation between pre- and post assessments rather than absolute score
    • No conclusion from meta-analysis
    • Reasons for variability between test findings and subjective symptoms:
      – Failure of tests to detect subtle impairment
      – Ability of central compensation to recover from noted vestibular deficit
      – Failure to test each of the five sensory vestibular organs
Effects of Cochlear Implantation on Vestibular Function

- **Subjective assessment**
  - Other studies reviewed
  - All agree that post-CI dizziness is mostly mild
  - Incidence of NEW onset dizziness following CI is relatively low
  - Pre-CI and post-CI incidence of dizziness is about 40 vs. 60%
    - Post CI dizziness improves with time
  - Question about whether activation of the implant helps reduce dizziness
  - Older studies may report higher incidence of dizziness post-CI
    - Effect of ‘soft surgery’ techniques?

- **Study by Basta et al., 2008**
  - Vestibular testing pre-and post-CI – VNG, Rotational Chair, HIT, VEMP
  - cVEMP recorded intraoperatively – present in all patients
  - 62.5% (10/18) patients with preoperatively normal VEMPs had complete loss of VEMP response postoperatively
    - 5/10 with subjective persistent dizziness
  - Identified different mechanisms of postoperative dizziness
    - Acute, short term dizziness – transient vestibular deficit of various origins
    - Chronic, persistent dizziness – dysfunction of saccular macula; likely due to insertion trauma created by insertion of the implant electrode into the inner ear
    - Suggest that possible co-activation of inferior vestibular nerve by electrical stimulation may plan an additional role (contra to prior study)
Effects of Cochlear Implantation on Vestibular Function

- Study by Todt et al., 2008 (Basta coauthor)
- Asked question: does surgical technique affect postoperative VEMP response?
- Compared cochleostomy and round window approaches to electrode insertion
- VEMP conserved significantly more often with RW approach
- Advocate for use of RW approach for electrode insertion

Effects of Cochlear Implantation on Vestibular Function: Histopathology

- Tien and Linthicum, 2002
- Studied 11 pairs of temporal bones, non-CI ear as control
- Significant damage noted in 6/11 patients, or 55%
- Most common findings:
  - Fibrosis in vestibule
  - Saccule membrane distortion
  - New bone formation
  - Reactive neuromas
- Scala vestibuli involvement (damage to osseous spiral lamina, basilar membrane in basal turn) highly correlated with vestibular damage – 75%
Possible Mechanisms of Dizziness Post - CI

- Creation of bilateral vestibular deficit (by implantation of ear with better function); caution with bilateral implants
- Transient vestibular paresis
- BPPV – surgical drilling may dislodge otoconia (bilateral)
- Development of endolymphatic hydrops; possible mechanisms:
  - Obstruction of endolymphatic flow at ductus reuniens
  - Obstruction cochlear duct
  - Damage to lateral wall cochlea may cause hydrops in cases where DR and cochlear duct remain patent
- Progressive fibrosis with reduced vestibular response
- Have you seen post CI (new onset) Meniere’s disease?
- Effect of MD in patients with CI – effect on programming

Effects of CI Electrical Stimulation on Vestibular Function?

- Buchman et al., 2004
- Performed vestibular assessment pre and post CI in 86 patients
- DHI, ENG, Rotary chair, CDP
- Testing performed preop, 1-, 4- month, 1-, 2- year post op
- Findings:
  - No significant post-CI deficits on testing
  - Some improvement noted after CI activation with device ‘on’ in CDP – improved postural sway in conditions 5 & 6 (vestibular)
Can Vestibular Effects of CI be Minimized?

- **Choice of ear**
  - Good practice to avoid CI in an ear with only vestibular function
- **Surgical technique**
  - Evidence that 'soft surgery' techniques important in preserving good vestibular function
  - Most important to avoid s. vestibuli insertion
  - Round window approach generally preferred to cochleostomy (more variable)
  - Slow electrode insertion
  - Steroid use
- **Choice of electrode**
  - Some studies have shown that deeper insertion/longer electrodes may be correlated with increased incidence of trauma to basilar membrane
  - Recent study (Nordfalk et al., 2015) shows deep electrode insertion not correlated with loss of vestibular function, but electrodes confined to ST (flat-panel CT)
- **Importance of counseling**

Should Vestibular Testing be Performed Pre-CI?

- No conclusive evidence that pre-CI testing is useful or cost-effective
- Consider limited battery of tests, excluding calorics
  - HIT
  - cVEMP
- Perform on a case-by-case basis
  - If patient symptomatic with dizziness pre-CI
  - History of past vestibular event/deficit
  - Consider in cases of bilateral CI

Current Duke study to determine if soft surgery technique more likely to result in better vestibular outcomes (funded by MedEl Corp)
Case Study #1 E.L.

- 70 year old male presents for evaluation of cochlear implantation
- Bilateral profound SNHL; small amount residual hearing left ear (wears hearing aid)
- Poor SDSs bilaterally – HINTs: bilateral 10%; left 0%; right 0%
- CT temporal bone – normal study
- MRI – contraindicated due to metal in body

Case Study #1 E.L.

- Cochlear implant performed on 6/30/11
- Nucleus CI512
- 5-mm ossification at basal turn, otherwise uneventful surgery with full insertion
- Activated in Mountain Home VAMC
- Subsequently device failure suspected and confirmed
- Re-implantation with Freedom Contour on 3/14/12
- Further ossification basal turn; full insertion; good NRTs
Case Study #1 E.L.

- Wife called DVAMC 3/23/12 reporting that patient experiencing dizziness since surgery, now must walk with a cane
- DHI score 48/100 (c/w preop 4/100)
- Limited vestibular testing performed:
  - cVEMPs absent bilaterally
  - CDP testing showed severe dysfunction pattern
  - Oculomotor testing normal
  - No preop testing was performed
- Counseled on fall prevention

Case Study #1 E.L.

- Follow up testing June 2012
- DHI 20/100 (improved; mild handicap)
- CDP: still shows severe dysfunction
- ENG – right sided vestibular weakness
- No BPPV
- Vestibular rehabilitation therapy
- CT scan 5/24/12: Implant in good position
- Performance similar to that with first implant, 83% on HINT sentences
- Dizziness improved; not using cane; working on his farm
Case Study #1 E.L.

- Discussion
  - Revision implant – increased incidence of dizziness/vestibular dysfunction?
  - Effect of ossification? More traumatic removal of original electrode?

Case Study #2 F.W.

- 70 year old female with reported gradual subjective hearing loss over past 20 years (1986), seen for cochlear implant eval on 8/2/13
- Bilateral ear fullness, present for past 40 years
- No history of ear infections, surgery
- History of noise exposure (flight nurse)
- Bilateral tinnitus
- Hearing aid use since 1988
- Dizziness – wavering vision in response to loud sounds or pressure changes. Two cases of ‘dizzy spells’ with nausea in 2008 and 2009
- Audio: moderate to profound SNHL bilaterally; SDS R: 20%; L: 16%
Case Study #2 F.W.

- Prior vestibular testing; Mountain Home VA
  - VEMP c/w SSC dehiscence
- CT temporal bone – MHVA radiologist read as: opacification mastoid on left; otherwise unremarkable
- MRI – MHVA radiologist read as: normal
- Based on history and VEMP testing suspected SCD
- Vestibular testing repeated at DVAMC 3/21/13: VEMP C/W left SCD

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Case Study #2 F.W.

- 8/29/13: **right** CI, Cochlear Nucleus Freedom
- CI performance: AZBio sentences in quiet 72% with CI alone; 94% bimodal
- Cannot test AR or word recognition at high intensity (e.g. 95 dB) – if loud sounds presented, left eye flutters and patient becomes dizzy; otherwise no dizziness
CI in patients with superior canal dehiscence

- Puram et al., 2015; Cochlear Implants International
- Reviewed results for 8 CI recipients, 5 unilateral and 3 bilateral
- One patient had SCD syndrome; 7 patients asymptomatic
- Of 7 with asymptomatic dehiscence, post CI rates of dizziness similar to non-SCD patients
- Speech perception abilities were slightly poorer in SCD patients than in non-SCD patients overall, although improved substantially c/w preop
  - However, duration of deafness significantly greater in SCD than in non-SCD group
  - Therefore poorer performance not related to SCD

CI in patients with superior canal dehiscence

- Puram et al., 2015; Cochlear Implants International
- In SCD syndrome patient, postoperatively had preserved vestibular function, improved QoL, and reduced dizziness symptomatology (same ear)
  - Patient actually had improved vestibular function and symptoms post CI (ENG improved)
  - Complete resolution of Tullio phenomenon
  - From this one case, no evidence of contraindication for CI in patients with SCD
Learning Objectives revisited

• List the risk factors for potential vestibular dysfunction related to cochlear implant surgery
  – Cochlear trauma with injury to saccule
  – Trauma may be minimized by
    • Round window insertion
    • ‘Soft surgery’ techniques – slow atraumatic electrode insertion, use of steroids

Learning Objectives revisited

• Describe the incidence of complaints of imbalance of older adults (>60 years) in comparison to younger cochlear implant recipients
  – Although some studies report greater incidence of dizziness post CI in older patients, more recent studies do not
  – Possible benefit of newer surgical techniques that minimize trauma?
Learning Objectives revisited

• Describe the vestibular tests that are most likely to reflect impairment post implant surgery
  – VEMP, which measures saccular function, is most likely to show a postoperative deficit that is meaningful