The Importance of Binaural Hearing

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Presentation Overview

- Definition of Terms
- Importance of Binaural Hearing
- Bilateral Hearing with Hearing Aids
- Implantable Hearing Solutions
  - Bimodal Hearing
  - Bilateral Hearing
- Candidacy Criteria
- Clinical Management
- Summary
Bimodal use is on the rise

Rationale for bimodal fittings:
- Expanding candidacy criteria
- Improved CI technology/performance
- Improved power aids w/ DSP + feedback cancellation

Potential benefits:
- Better hearing performance in background noise\(^1\)
- Music appreciation\(^2\)

Bilateral is a consideration

• 5% of adults who qualified for cochlear implantation and pursued treatment were bilaterally implanted\(^1\)
  – Based upon internal data of three manufacturers
  – 36,398 pursued unilateral and 1,882 pursued bilateral

Definition of Terms
A Few Terms Explained

- **Bilateral**: Both ears
- **Bilateral cochlear implantation**: CIs placed in each cochlea of an individual patient
- **Bimodal**: Two different modes of stimulation
- **Bimodal Hearing/Bimodal Devices**: CI in one ear, Hearing Aid (HA) on the other ear
- **Binaural Hearing/Binaural Processing**: Integration in the central auditory pathways of bilateral sound input

* A CI and an optimally fitted HA on the non-implanted ear, two normally hearing ears, two hearing aids, or two CIs can provide binaural processing for some patients.
# A Few Terms Explained

<table>
<thead>
<tr>
<th></th>
<th>Side One</th>
<th>Side Two</th>
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</thead>
<tbody>
<tr>
<td><strong>Bilateral Cochlear Implants</strong></td>
<td>Cochlear Implant</td>
<td>Cochlear Implant</td>
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<tr>
<td><strong>Bimodal</strong></td>
<td>Cochlear Implant</td>
<td>Hearing Aid</td>
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<tr>
<td><strong>Binaural Hearing/Processing</strong></td>
<td>Cochlear Implant or Hearing Aid may provide binaural processing</td>
<td>Cochlear Implant or Hearing Aid may provide binaural processing</td>
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*Binaural Hearing assumes processing of two signals throughout the central auditory system*
Cochlear Implant Candidacy Criteria
Adult Candidacy Criteria

• Adults: Individuals 18 years of age or older who have bilateral sensorineural hearing impairment and obtain limited benefit from appropriate binaural hearing aids.

• These individuals typically have moderate to profound hearing loss in the low frequencies and profound (≥ 90 dB HL) hearing loss in the mid to high speech frequencies.

• Limited benefit from amplification is defined by test scores of 50% correct or less in the ear to be implanted (60% or less in the best-aided listening condition) on tape-recorded tests of open set sentence recognition.
## Evolution of Adult Candidacy Criteria

<table>
<thead>
<tr>
<th></th>
<th>1985</th>
<th>1990</th>
<th>1998 (CI24M)</th>
<th>2000 (CI24R/CA) to Current (CI512)</th>
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<tbody>
<tr>
<td><strong>ONSET of Hearing Loss</strong></td>
<td>Postlinguistic</td>
<td>Postlinguistic</td>
<td>Pre &amp; Postlinguistic</td>
<td>Pre &amp; Postlinguistic</td>
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<tr>
<td><strong>DEGREE of SNHL</strong></td>
<td>Profound</td>
<td>Profound</td>
<td>Severe-Profound</td>
<td>Moderate-to-profound -bilateral sensorineural hearing loss</td>
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<tr>
<td><strong>ADULT Open-set sentences</strong></td>
<td>0%</td>
<td>0%</td>
<td>40% or less</td>
<td>≤ 50% sentence recognition in ear to be implanted (aided) ≤ 60% in contralateral ear and binaurally (aided)</td>
</tr>
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</table>
Adult Candidacy Criteria

Audiometric candidacy ranges
Moderate-to-profound SNHL in both ears

Speech recognition criteria

Limited benefit from amplification defined as preoperative test scores:
<50% sentences in ear to be implanted
<60% bilaterally (best aided condition)

Medicare criteria differs slightly:
≤ 40% sentence recognition in the ear to be implanted (aided)
Case Study

52 y.o. CI – Right Ear

Pre-op

<table>
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<tr>
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<th>Aided Scores*</th>
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<tr>
<td>HINT</td>
<td>12%</td>
</tr>
<tr>
<td>CUNY</td>
<td>19%</td>
</tr>
<tr>
<td>CNC</td>
<td>0%</td>
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Post CI

<table>
<thead>
<tr>
<th></th>
<th>Scores</th>
</tr>
</thead>
<tbody>
<tr>
<td>HINT</td>
<td>87%</td>
</tr>
<tr>
<td>CUNY</td>
<td>92%</td>
</tr>
<tr>
<td>CNC</td>
<td>78%</td>
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</table>

A - best aided  
C - CI right ear

*Performed in best aided condition

Note: Left side is dead ear
The Importance of Binaural Hearing
What is Binaural Hearing?

- Inputs from each ear travel up ipsilateral and contralateral brainstem pathways where the 2 inputs are compared and processed at various nuclei before reaching the auditory cortex.

- Binaural hearing allows the listener to take advantage of a variety of auditory cues such as interaural level and time differences that result in specific benefits.
Potential Benefits of Binaural Hearing

• Improved speech perception in quiet and in noise, from:
  – Binaural redundancy/summation effects
  – Spatial separation (binaural squelch and head shadow effects)
• Improved sound localization
• Improved:
  – Ease of listening,
  – Perceived benefit and satisfaction
  – Quality of life
Measured Effects of Binaural Hearing

- **Head Shadow Effect** is a *physical phenomenon*
  - This occurs when the head obstructs sounds arriving at the ears from different locations. Binaural hearing allows the listener to always have available the ear with the better signal-to-noise ratio (SNR)

- **Binaural Redundancy** and **Binaural Squelch Effects** are products of *central auditory processing*
  - These occur when inputs from both ears are analyzed throughout the auditory pathways
  - These are signs of the ability of the auditory nervous system to integrate, fuse, and use information from the two ears
  - In effect helps the brain “tease out” the desired auditory signal from the background noise
Head Shadow Effect

- Using the ear with the better SNR in spatially separated speech and noise
  - With one implant or hearing in only one ear in certain listening situations the implanted ear or hearing ear may have the less favorable SNR
  - Spatial separation benefits can occur from the head shadow effect and having 2 functioning cochleae
Listening using the ear with the better SNR to improve performance

- Large and robust benefit of head shadow

Binaural Redundancy Effect

• Simply means **two ears are better than one** when speech or speech in noise are from the same location, because each ear receives the same input.

• Several studies have shown a significant binaural summation (redundancy) effect for understanding words and sentences compared to listening with either cochlear implant alone\(^1,2\)

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Binaural Redundancy Effect

- Auditory system’s ability to use redundant information for better performance when the same signal arrives at both ears

- Difference between bilateral and better ear performance in spatially coincident speech, or speech and noise
Binaural Squelch

Advantage of adding the ear with the poorer SNR compared to listening with the better SNR ear alone

• Buss et al (2008) saw emergence of binaural squelch effect in some subjects between the 6 and 12 mo test intervals, with a highly significant mean increase in magnitude of the advantage, from 3.3% to 10.6%¹

Bilateral Hearing with Hearing Aids
Bilateral hearing refers to the ability to receive a signal on two sides, this can be achieved using:

- Two normally hearing ears
- Two hearing aids or Baha® devices
- A cochlear implant and a hearing aid (bimodal hearing)
- Two cochlear implants
Bilateral Hearing with Hearing Aids

- In 1990 Vanderbilt University and the Department of Veterans Affairs cosponsored a conference designed to address current clinical and research issues on hearing aids.
- Following the conference, a consensus statement was developed on hearing aid selection procedures for adults.
- “Unless clear contraindications exist, binaural hearing aids should be considered the preferred fitting for the prospective hearing aid user.”
  - Bilateral hearing aid fittings have been standard practice in the hearing aid industry for years!

Bilateral Hearing with Hearing Aids

• For patients with bilateral hearing loss, bilateral hearing aid fittings have been the standard practice for many years
• Reasons for bilateral hearing aid fittings include¹:
  – Better understanding of speech
  – Better understanding in group and noisy situations
  – Better ability to tell the direction of sound
  – Better sound quality
  – Wider hearing range
  – Better sound identification
  – Keep both ears active resulting in potentially less hearing loss deterioration
  – Hearing is less tiring and listening more pleasant
  – Feeling of balanced hearing
  – Consumer preference
  – Customer satisfaction

¹ As reported by the Better Hearing Institute, http://www.betterhearing.org/hearing_solutions/binaural.cfm?printfriendly=1
• We know that **Two Ears ARE Better Than One**
  – This may mean different things for different individuals. It could mean:
    • Using two hearing aids/Bahas®
    • Using a cochlear implant and a hearing aid
    • Using two cochlear implants

How do you determine which scenario is best for each patient?
Clinical Considerations

- Binaural Hearing Solution
  - Bimodal Hearing Aid & CI
    - Bilateral Hearing Aid
    - Bilateral CI
  - Unilateral Hearing Aid
    - Unilateral Hearing Aid

Why only one hearing solution?
Implantable Hearing Solutions
More potential for Bimodal users than you think

• Severe to profound hearing loss in the US

8.4 million Hearing Aid (HA) users in U.S.¹

~840,000 severe to profound² (10%)

~523,000 potential cochlear implant candidates³

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3. Cochlear internal estimates.
Bimodal versus Bilateral: Candidacy Considerations

- **Current status**
  - Unanimous agreement by panel that bilateral implantation provided improved auditory perception in the majority of cases\(^1\)

- **When to consider *bimodal devices*?\(^2\)**
  - Residual hearing in the non-implanted ear
  - Good HA performance in that ear
  - When there is any possibility of benefit

- **When to consider *bilateral implantation***?
  - Little or no residual hearing in non-implant ear
  - No significant benefit, or even a decrement in performance, from hearing aid use in the non-implant ear

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Bimodal Hearing: 
More Common Today

• Broadened indications for implant candidacy: more individuals with potentially useable residual hearing
  - 80% (42 of 53) used bimodal hearing for >8 hours on average and all rated the bimodal condition superior to CI alone¹
  - 60% (15 of 24) of bimodal users report using hearing aid more than 50% of the time²

• Reviews of existing literature support fitting of a contralateral hearing aid as the first line of treatment to CI recipients with residual hearing³,⁴

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Potential Advantages of Bimodal Hearing\textsuperscript{1,2}

- Localization and spatial hearing
  - Interaural time, intensity, phase differences at the 2 ears
- Complimentary cues
  - Combining low-frequency information from the hearing aid with high-frequency information from the implant can help, for example by separating voices in noise
- Sound quality, music perception and enjoyment
  - Improved quality by adding fundamental frequency, acoustic pitch and fine temporal structure not available through current cochlear implants

Bimodal Speech Recognition

• 19 Nucleus 24 recipients using a well-fit digital HA on the contralateral ear
• Test measures: roaming speech recognition task and localization
  – Stimuli: CNC words presented at a roving level of 60 dB SPL (+/- 3 dB), presented randomly from an array of 10 loudspeakers
  – Subjects cued with “ready” and allowed to turn toward the loud speaker prior to repeating the stimulus word
  – Localization: subject identified the loud speaker location by speaker number
  – Conditions: HA, CI and CI+HA
• Mean speech recognition results
  – HA = 12% words, 37% phonemes
  – CI = 39% words, 66% phonemes
  – CI+HA = 53% words, 76% phonemes
  – Conditions were significantly different from each other for both words and phonemes
  – No subject performed poorer with CI+HA than either monaural condition

Case Study

36 y.o. CI Right Ear + HA Left Ear

Pre-op best aided

<table>
<thead>
<tr>
<th></th>
<th>R</th>
<th>L</th>
<th>AU</th>
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<tbody>
<tr>
<td>WRS %</td>
<td>0</td>
<td>32</td>
<td>36</td>
</tr>
<tr>
<td>HINT-Q* %</td>
<td>0</td>
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Post-op (6 mos)

<table>
<thead>
<tr>
<th></th>
<th>R-CI</th>
<th>L-HA</th>
<th>AU</th>
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</thead>
<tbody>
<tr>
<td>WRS %</td>
<td>80</td>
<td>32</td>
<td>dnt</td>
</tr>
<tr>
<td>HINT-Q* %</td>
<td>92</td>
<td>48</td>
<td>100</td>
</tr>
<tr>
<td>HINT-N# CI+HA</td>
<td>80</td>
<td>dnt</td>
<td>100</td>
</tr>
</tbody>
</table>

*60dB SPL #+10/SNR
dnt = did not test
A – Aided SF
C - CI right ear
Bimodal Localization

- Localization abilities reported as RMS error
  - HA = 61° error
  - CI = 54° error
  - CI+HA = 39° error
- CI+HA localization was significantly better than either monaural condition
- The HA and CI conditions were not significantly different
- Important to maximize audibility with HA through 2 kHz

Bimodal Sound Quality and Music Perception

• In general, implant recipients perform poorly on tests of pitch perception and melody recognition\(^1\)

• In a study of Music Perception in Nucleus\(^\circledast\) CI Users:
  – Bimodal users performed significantly better on all tests than those using only electrical stimulation\(^2\)

• Comparison of CI and CI+HA on familiar melody recognition show the majority of recipients had significant improvements in the CI+HA condition\(^3\)
  – Some data suggesting amount of benefit is related to amount of contralateral residual hearing

• Unilateral implant recipients who attempt but discontinue hearing aid use in the contralateral ear
  – <25% of 72 unilateral implant recipients with residual hearing (PTA <110 dB) used their hearing aid more than 50% of the time
  – 40% of implant recipients with a PTA of < 100 dB reported consistent hearing aid use

• Documented lack of improvement or a decrement in performance in the bimodal condition compared to the unilateral CI condition

Trends with Binaural Hearing Solutions

- Bimodal fitting recommendations are increasingly becoming the standard of care
- For a small population, Bilateral implantation may be appropriate and is a growing trend

Adult Candidacy Considerations for CI’s

• To ensure maximal potential for binaural processing, the *most desirable* candidates have¹:
  – Post-lingual onset of hearing loss
  – Relatively short duration of profound hearing loss (e.g. less than 15 years),
  – *or* consistent and continued use of amplification in both ears up to implantation

The potential benefits of bilateral hearing with cochlear implants are much the same as bilateral hearing with hearing aids. Benefits of bilateral cochlear implants may include:

- **Improved speech understanding in noise**
- **Improved sound localization**
- **Improved patient-perceived outcomes**

- Patient never without sound
- Sound more balanced
- Hearing speakers from both sides

Demonstrated in numerous studies
Improved Speech Recognition with Bilateral Cochlear Implants

- Study compared outcomes of 33 adults with bilateral CIs with 40 adults with unilateral CI

- Improved speech recognition in quiet
  - On average:
    - Adults scored 19% higher on sentences
    - Adults scored 24% higher on words
  - Than did unilateral cochlear implant users

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Improved Speech Understanding in Noise with Bilateral Cochlear Implants

• Data showing improvement in speech understanding in noise for some patients with bilateral cochlear implants were reported in the literature as early as 1988¹

• In research studies, improvement in speech understanding in noise is largely due to the head shadow effect, and to a lesser extent for some patients, the binaural squelch effect and the binaural redundancy effect²,³

• Improvements have been demonstrated in many recent studies in both adults and children²-⁴

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Improved Speech Understanding in Noise with Bilateral Cochlear Implants

- 15 bilateral subjects evaluated after 3 & 6 months experience
- Speech recognition using BKB-SIN test
  - Speech at 65 dB SPL from a loudspeaker at 0 degrees (frontal) and noise from either 0 degrees or +/- 90 degrees (sides)
  - SNR for 50% correct determined when listening with each implant alone and while listening with both implants
- Findings:
  - Significant benefit of listening with two ears in spatially separated speech in noise (defined as >3.1 dB advantage in the bilateral condition over unilateral conditions)
  - Benefit was greater after 6 months listening experience than after only 3 months listening experience

Improved Sound Localization with Bilateral Cochlear Implants

• Improved sound localization with bilateral cochlear implants has been reported in the literature since the 1990s\(^1\)

• Improvement in localization ability is due to integrating independent information from each ear throughout the auditory pathways

• This ability has been demonstrated in multiple recent studies with cochlear implant recipients\(\textit{e.g.}\)\(^2,3\)

Improved Localization with Bilateral Cochlear Implants

• Study compared outcomes of 33 adults with bilateral CI with 40 adults with unilateral CI

• Findings:
  – Enhanced sound localization
    • Adults with bilateral cochlear implants had significantly more success identifying the location of sounds
    • Average localization precision was 25 degrees more accurate than unilateral subjects

With a second CI, precision in localizing sound more than doubles!

Mean angular error:

Unilateral CI: $67^\circ$

Bilateral CI: $24^\circ$

Patient-Perceived Outcomes

• Favorable patient-perceived outcomes with bilateral implants have been reported in the literature since 1992¹

• Improvements in self-perceived outcomes are likely due to increased performance outcomes and localization abilities

• Positive bilateral outcomes have been demonstrated in multiple recent studies with cochlear implant recipients²,³

• *Patient-perceived outcome data are based on self-assessment metrics and as a result, results can be variable*

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Patient-Perceived Outcomes

- Retrospective study using factor analysis from two questionnaires
  - Hearing Handicap Inventory for the Elderly (HHIE)
  - Hearing Handicap Questionnaire (HHQ)
- 35 bilateral recipients, 106 unilateral recipients, 42 with one cochlear implant and one hearing aid
- Findings:
  - The least perceived handicap reported was by the bilateral implant group
  - Bilateral group also perceived significantly less handicap than the other groups on the Social Restriction subscores

Patient-Perceived Outcomes

• APHAB questionnaire data collected during a multi-center study of 37 simultaneously implanted adult cochlear implant users (using Nucleus 24)
• First administered after a 3 week period during which bilateral CI recipients used only one implant (the better ear) then was re-administered after a period of using the bilateral implants again
• Findings:
  – Subjects perceived their performance with the bilateral implants as significantly better than with a unilateral implant on the best-performing ear on all three communication subscales of the APHAB
  – No significant difference on the Aversiveness of Sounds subscale

Clinical Management
Hearing Healthcare Team
Hearing Healthcare Team

Who’s on the Team?
Hearing Healthcare Team

Who’s on the Team?

Hearing Instrument Specialist
Hearing Healthcare Team

Who’s on the Team?

ENT Physician
Hearing Healthcare Team

Cochlear Implant Audiologist

Who’s on the Team?
Who’s on the Team?
Hearing Healthcare Team

A Happy Patient
Our Team

- Dr Mason and partner physicians
- In-office audiologists
- Baystate Medical Center Cochlear Implant Program
- Community audiologists and hearing instrument specialists
- Patients!
Clinical Management of the Bimodal Patient

• All hearing healthcare professionals should feel comfortable in providing a bimodal hearing solution
  – With changing trends, it is very likely that you will continue to treat this patient population
• Know a brief history…
  – When were they implanted
  – What is their ability
  – Overall satisfaction levels
• Remember the following…
  – A unilateral cochlear implant patient has already met a best aided binaural speech discrimination score of <60% prior to cochlear implantation
  – Patient must have a bilateral severe to profound sensorineural hearing loss
6 Steps to a Bimodal Patient

Step 1: Create 3 HA Programs

Step 2: Match Loudness

Step 3: Determine Preferred HA Program

Step 4: Balance Loudness for CI + HA

Step 5: Fine Tune the HA for Bilateral Comfort

Step 6: Counsel on Continued HA Use
Step 1: Create 3 HA Programs

To start: Make sure the HA and CI are both ON

• Program 1: Prescription of Choice

• Program 2: Low Frequency Cut
  -6 dB/octave below 2k Hz

• Program 3: Low Frequency Boost
  +6 dB/octave below 2k Hz

Verify fit by using probe microphone.
Step 2: Match Loudness

To start: HA ON and CI OFF

• Balance HA programs 2 and 3 to program 1

• Adjust the HA gain of programs 2 and 3 until the patient reports equal loudness when compared to program 1

• This is a task for loudness only
Step 3: Preferred HA Program

To start: HA ON and CI OFF

• Have the patient listen to all 3 HA programs

• Which program provides the best sound quality and/or speech understanding?

• This becomes the “preferred” program
Step 4: Balance Loudness

To start: HA and CI OFF

- Turn CI ON first, then turn HA ON
  - things may sound a bit loud
- Point to the side where speech is loudest and adjust HA gain accordingly
  - If they point to CI, increase HA gain
  - If they point to HA, decrease HA gain
- Aim for equal loudness between ears
Step 5: Fine Tune for Comfort

To start: Both HA and CI ON

- Present recorded speech at 50 dB SPL
  - Adjust compression ratio/threshold to maintain equal loudness between HA and CI

- Present recorded speech at 85 dB SPL
  - Adjust MPO to not exceed loudness discomfort levels
Step 6: Counsel on HA Use

• Counsel on the benefits of binaural hearing

• Set appropriate expectations of speech understanding with the cochlear implant vs. the hearing aid

• Discuss binaural assistive listening devices (i.e., HATIS)

• Encourage a HA fine tuning appointment following every cochlear implant mapping session
Summary
Key Messages

- TWO ears are better than ONE

- Bilateral hearing aids are the standard of care

- Bimodal hearing is an option for those who qualify for cochlear implantation

- The potential benefits of hearing with bilateral cochlear implants are much the same as hearing with bilateral hearing aids.
Thank you!

Theodore Mason MD
Ear, Nose & Throat Surgeons of Western New England

www.entassociates.org
www.cochlear.com

Download presentation slides at www/ihsinfo.org/convention
Questions?