Bimodal Hearing Aid Fitting Guidelines

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ABSTRACT

In a bimodal fitting, one ear is stimulated acoustically with a hearing aid and the other is stimulated electrically with a cochlear implant.

To bring bimodal benefits to all children and adults with unilateral implants and aidable hearing in the contralateral ear, Oticon has implemented a bimodal fitting guide in the Genie fitting software. As developed by Carisa Reyes, Staff Audiologist at Boys Town National Research Hospital, the bimodal fitting flowchart serves as a guide to clinical audiologists as they navigate the bimodal fitting process. The goal is to provide a logic- and evidence-based method for decision-making, yet keeping in mind the constraints in everyday clinical practice.

Based on the latest knowledge on bimodal research, this paper explains the rationale, the recommended strategies, the procedures and the caveats of the bimodal fitting.

- Candidates for bimodal fitting
- When to fit the hearing aid
- How to fit the hearing aid for bimodal patients
- Bimodal flowchart
- Evaluation of benefits
- Case Studies

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The bimodal flowchart takes into account the four fitting approaches: wideband fitting, restricted bandwidth fitting, use of frequency lowering and loudness balancing. The chart is available in Genie when you fit Oticon Dynamo or Sensei Super Power.

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Candidates for bimodal fitting:

More than half of those receiving a cochlear implant have aidable hearing in the non-implanted ear[1]. If these recipients are fitted with a hearing aid in the non-implanted ear, access to bilateral and binaural cues (such as those arising from head shadow and redundancy) as well as complementary acoustic cues (such as fundamental frequency) may enhance cochlear implant performance. In this guideline, bimodal stimulation refers to the use of a cochlear implant in one ear and a hearing aid in the opposite ear and bimodal benefit refers to performance improvement with the hearing aid over performance with the cochlear implant alone. Even recipients with significant hearing loss in the non-implanted ear demonstrate bimodal benefit[2-4]. For those who do not obtain bimodal benefit for speech recognition in noise[5], other benefits such as enhanced music and pitch perception may still occur[6-9]. In addition, many studies have documented more natural sound quality and improved ease of listening with bimodal stimulation[3,10-15]. Finally, bimodal stimulation can facilitate spoken language and literary skills in young children who subsequently receive a second side cochlear implant[16-18]. The provision of bilateral hearing is considered the standard of care for cochlear implant recipients[19,20]. Therefore, all unilateral cochlear implant recipients who have some degree of aidable residual hearing in the contralateral ear should be considered candidates for bimodal stimulation.

Fitting a hearing aid in the non-implanted ear gives acoustic cues that may enhance CI performance

When to fit the hearing aid:

The recommended time between activation of the cochlear implant and bimodal stimulation varies for different clinics[21,22]. Some argue that delaying bimodal stimulation can facilitate the adjustment to the cochlear implant. However, cessation of hearing aid use or delaying the hearing aid fitting has not been shown to improve *long-term* outcomes. Many cochlear implant candidates are already fitted with bilateral amplification so continued use of the contralateral hearing aid after implantation will allow for continued bilateral stimulation. Immediate hearing aid use will allow the user to obtain the benefits associated with bimodal stimulation sooner rather than later. Continued use of amplification may also facilitate the patient's adjustment to the cochlear implant. There may be isolated cases where this approach would not be appropriate, but in general, bimodal fitting is recommended as soon as possible.

If further optimization of the bimodal fitting is to be undertaken, it has been recommended that this be completed once the cochlear implant program is stable[23,24]. However, clinical judgment may dictate that this be completed sooner (as long as the cochlear implant is set at a comfortable level) because it may take several months to arrive at a stable program.

How to fit the hearing aid for bimodal patients:

Unfortunately, studies have found that many bimodal users have hearing aids that are fit sub-optimally (i.e., set below targets)[25,26]. It is beyond the scope of this paper to outline the standard hearing aid fitting process, but at a minimum, recommended guidelines for proper selection and verification of amplification should be followed to ensure maximum audibility and comfort of sounds of varying input levels[27,28].

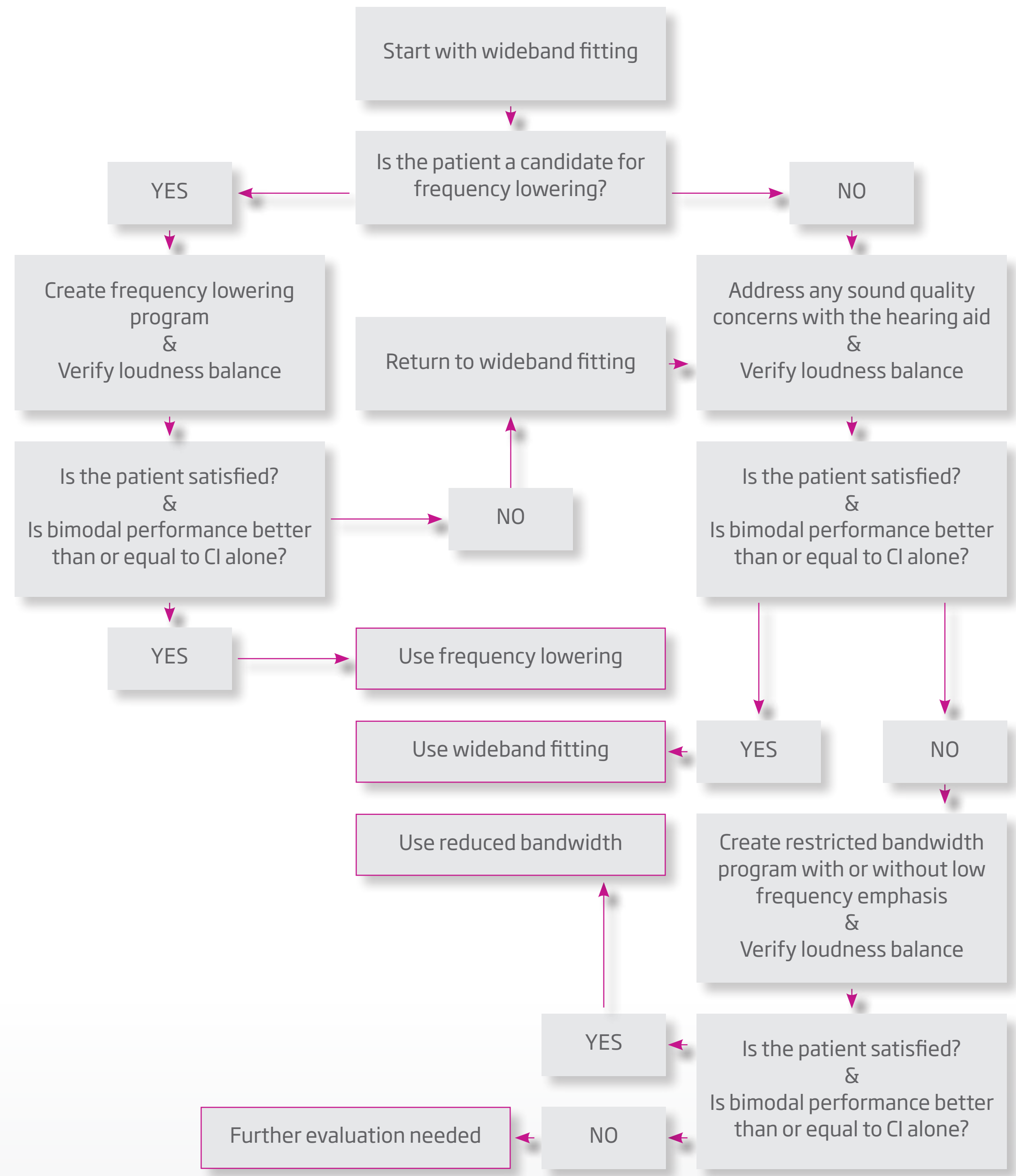
Not a "one-size-fits-all" procedure. The approach that provides the greatest benefit will likely vary among patients

It has been suggested that optimizing the hearing aid fitting for bimodal use (by considering frequency response and loudness balance) may result in greater benefit over standard hearing aid fitting[2,3,29,30]. However, there is currently no single approach to bimodal fitting that is universally accepted[21,22]. Additionally, there is conflicting evidence that indicates that further optimization of the hearing aid for bimodal use beyond fitting to target using proper verification methods does not result in superior outcomes[31]. Nevertheless, certain fitting strategies may be considered and explored for bimodal recipients as the literature suggests these approaches have the potential for improving outcomes. It should be noted that the approach that provides the greatest benefit or that subjectively provides the most satisfactory sound will likely vary among recipients[32].

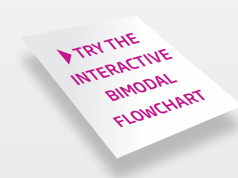
Bimodal decision-making flowchart:

The accompanying Bimodal Fitting Flowchart was developed to serve as a guide for the bimodal hearing aid fitting process. This is not intended to be a "one-size-fits-all" procedure that is applicable to every bimodal listener. The cochlear implant population is extremely diverse and clinical judgment may warrant that a different approach be taken for a particular patient or patient population. For

Bimodal flowchart.



All unilateral cochlear implant recipients with aidable residual hearing in the other ear are candidates for hearing aid use. This flowchart provides an evidence-based, yet practical, method for fitting a hearing aid on a bimodal patient. The flowchart takes into account wideband fitting, restricted bandwidth fitting, use of frequency lowering and loudness balancing.



example, there may be varying considerations with adult versus paediatric hearing aid fittings, where in high frequency audibility may be more critical for the paediatric population[33].

A logical and evidence-based method for decision-making, keeping in mind constraints in everyday clinical practice

The goal of this model is to discuss the various approaches to hearing aid fitting for bimodal users that can be followed using a logical and evidence-based method for decision-making, yet keeping in mind the constraints that can be found in everyday clinical practice (e.g. time constraints, different professionals managing the hearing aid and cochlear implant, etc.). This guideline focuses on the hearing aid fitting. There will be instances where adjustment of the cochlear implant would be more appropriate.

The flowchart incorporates both the hearing aid frequency response and loudness balancing. These are discussed in greater detail below.

Wideband Fitting:

It is recommended to start with wideband fitting as bimodal benefits have been consistently demonstrated using this standard approach. Prior to obtaining the cochlear implant, a majority of candidates will have amplification already fitted using this approach.

Rationale: Apart from optimizing audibility and ensuring listening comfort, the goal of hearing aid fitting for cochlear implant recipients is to allow access to as many potential bilateral, binaural and complementary acoustic cues as possible in order to maximize bimodal benefits. These cues may include high frequency information that can potentially provide inter-aural level difference cues[34,35]. In addition, low frequency acoustic information may provide voice and musical pitch cues that are not transmitted well by the cochlear implant[7,36-38]. Altogether, these additional cues may contribute to improved localization, music perception and speech recognition (particularly in noise). Several studies have demonstrated significant bimodal benefits with this approach versus restricting amplification to the lower frequencies[32,39,40].

Recommended Strategy: Match targets for as wide a bandwidth as possible according to the appropriate prescriptive formula using real ear or simulated real ear measurements.

Restricted Bandwidth with or without low frequency emphasis fitting:

While it may be prudent to start with wideband fitting, it should be noted that many cochlear implant recipients have significant high frequency hearing losses and/or suspected dead regions in the non-implanted ear. It may not be possible to provide high frequency amplification or to utilize frequency lowering. Even if amplification of the mid to higher frequencies is possible, this may degrade performance in certain patients. Potential advantages over wideband fitting include improved battery life, preventing "off-frequency" listening and feedback reduction.

Rationale: Several studies have suggested that the majority of the bimodal benefit for speech perception is obtained from the lower frequencies[4,40-43]. One adult study found that their subjects demonstrated greater bimodal benefit when amplification was not provided beyond the edge frequency of the dead region[44]. More research is needed in this area but the approach of limiting high frequency amplification could be investigated in cases of "bimodal decrement" (poorer performance in the bimodal condition vs. with the cochlear implant alone) or where there is lack of objective and subjective bimodal benefit. This is supported by work by Mok et al. (2006; 2010)[45,46] who found that greater bimodal benefit was found in subjects with poorer mid- and/or high-frequency aided thresholds. Finally, a few authors have suggested or demonstrated that some bimodal users prefer and/or derive benefit from alternative frequency responses, including one that provides additional low frequency emphasis while de-emphasizing the higher frequencies[2,3,24,29].

Caveat: Sound localization may be poorer when utilizing this approach versus with wideband fitting or frequency lowering[32,35]. Because cutting out high frequency amplification will affect access to inter-aural level difference cues, this approach is not recommended as the initial fitting strategy for bimodal users.

Recommended Strategies: It should be noted that there is no single accepted method for determining how to restrict high frequency amplification for bimodal users. The following can be considered:

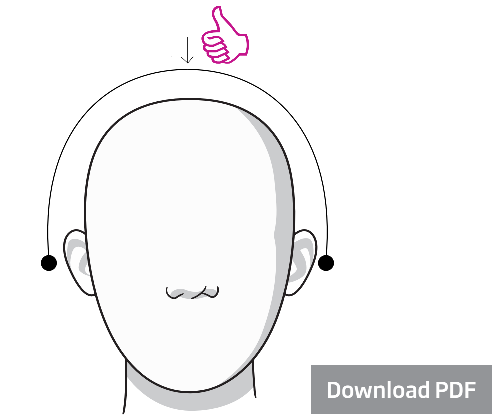
Based on the work of Zhang et al. (2014), the edge frequency of a cochlear dead region is determined using the Sweeping Psychophysical Tuning Curve (SWPTC) Test or the Threshold-Equalizing Noise (TEN) Test. Amplification is only provided up to the edge frequency of the dead region.

The SWPTC or TEN Test may not be clinically available and/or some patients (e.g. young children) may not be able to complete this type of testing. Because studies have shown that dead regions are oftentimes present when thresholds are in the severe to profound range[47], the dead region could potentially be estimated based on pure tone thresholds. That is, amplification is only provided up to frequencies where thresholds are equal to or better than 80-90 dB HL. Davidson et al. (2015) looked at the older paediatric to young adult population and the cut-off frequency was defined as the lowest frequency where the threshold was > 90 dB HL and the root mean square (RMS) average of the aided speech map for an input of 60 dB SPL fell below that threshold. Zhang et al. (2014), on the other hand, looked at adult subjects and selected the cut-off frequency based on 80 dB HL thresholds and compared this to TEN and SWPTC Test results. They found that cut-offs based on 80 dB thresholds matched with TEN Test results in 5 out of 11 cases and were always higher than cut-offs obtained from SWPTC Test results. This suggests that one may need to experiment with different cut-off frequencies to determine the one that results in the best possible outcomes.

Frequency Lowering:

In order to try to match frequency bandwidth for contralateral acoustic and electric hearing, high frequency audibility on the hearing aid needs to be maximized. Frequency lowering is now available in many commercial devices and has been used as a strategy to improve high frequency audibility with concurrent improvements in outcomes.

Rationale: For hearing aid users, frequency lowering improves high frequency detection and speech recognition[48,49]. For bimodal users, most research has not demonstrated significant benefit over standard fitting for subjects using frequency transposition[50] or frequency compression devices[51-53]. However, most of these studies indicated a high acceptance rate for frequency lowering and no decrement in performance. A recent study looking at older children and young adults[32] points to success using frequency lowering, with many subjects performing best in terms of localization, talker recognition and speech recognition with this approach. In addition, most subjects preferred frequency lowering over wideband and restricted bandwidth fittings.



Loudness balancing is an attempt to balance loudness between the CI and the hearing aid such as they are judged to be equally loud. The balance point for the electric and acoustic sound is found by increasing and decreasing the level of the hearing aid. Print and attach this picture to a wall. Ask the patient to indicate on the arc where sound is coming from. The balance is achieved when the overall sound produces a sensation that the stimulus is perceived directly in front of the head (arrow). For some patients this procedure may be easier than judgments of the relative loudness of each device.[59]

Candidacy: The Clinical Practice Guidelines for Paediatric Amplification[28] (American Academy of Audiology, 2013) indicate that frequency lowering can be considered if high frequency audibility is not possible using conventional amplification. The potential for improvement of audibility will depend on the patient's hearing loss, type of frequency lowering available and settings chosen. In general, a patient is a candidate for frequency lowering if the hearing aid fitting shows enough audible bandwidth to be able to take the inaudible high frequency components to a frequency where they can be made audible without causing harmful distortion.

Recommended Strategy: McCreery et al. (2013) showed that frequency lowering fittings that maximized audible bandwidth resulted in better outcomes versus fittings that did not[49]. The goal of maximizing audibility is also applicable to all forms of frequency lowering.

Procedure: Determine Maximum Audible Output Frequency (i.e., the highest frequency in the amplified speech signal that is audible) via real ear or simulated real ear measurements. Then, find the appropriate frequency lowering settings that maximize audibility and minimize distortion by using available tools (e.g. Verifit or the Frequency Lowering Fitting Assistants[48,54].

Loudness Balancing:
With properly fitted hearing aids and cochlear implants, sound should be as audible as possible and comfortable for varying input levels in both ears. Occasionally, however, recipients may require adjustments to address loudness concerns. For example, a low frequency gain increase may be needed to compensate for the reduction in perceived loudness when a restricted bandwidth fitting is utilized[32]. Alternately, a gain decrease may be needed due to binaural loudness summation[55].

Given differences in loudness growth with acoustic versus electric hearing[55] as well as other factors related to asymmetries created by signal processing differences between devices (amplitude compression characteristics, frequency range, noise reduction, etc.)[56,57], it may be difficult to match loudness for acoustic and electric hearing. Nevertheless, several authors have suggested or demonstrated that greater bimodal benefits for sound localization and speech recognition could be obtained with loudness-balanced devices[2,3,23,55].

Recommended Strategy: There are many procedures for loudness balancing described in the literature[2,23,45,58]. However, these typically require calibrated stimuli, tend to be time-intensive and may be difficult for patients to perform. Dorman et al. (2014)[59] found that although bimodal benefits can be obtained with unequal loudness between ears, the greatest benefit was seen when the acoustic signal was judged as equally loud to just noticeably softer than the CI signal or if the acoustic signal was perceived at "most comfortable loudness" level. The authors concluded that a high degree of precision is not necessary when attempting to balance loudness between devices. Although the procedure described below focuses on adjusting the hearing aid, there may be instances when it is more appropriate to adjust the overall loudness of the cochlear implant.

Procedure: If the hearing aid needs to be adjusted, apply gain and/or compression adjustments until a perception of equal (or close to equal) loudness with the cochlear implant is obtained. Alternately, adjustments can also be made when listening with the hearing aid alone so that a loudness rating of "most comfortable" is obtained. Complete real ear measurements at this final setting.
Dorman et al. (2014) 59 found the loudness "balance point" by using a graphic of a head with an arc to indicate where sound is perceived. Adjustments were made until the sound was perceived at the centre.

Note: The appropriate adjustment/s–such as overall gain or compression–will be dependent on the patient's perception and the hearing aid settings that can be manipulated (device-specific). Best clinical judgment should be utilized.

Caveat: Caution should be taken if significant gain reduction is required as this may negatively impact audibility. The patient may need to be counseled regarding this and/or re-evaluation of cochlear implant settings may be recommended.

The bimodal adjustments described in this paper can be carried out using the bimodal fitting panel in Genie. Use the loudness balance trimmer to increase or decrease the loudness across all frequencies simultaneously. Go to the Speech Rescue panel to apply frequency lowering. Use the High frequency On vs Off buttons to restrict the output bandwidth and/or give low frequency emphasis by sliding the low frequency emphasis trimmer.

Evaluation of benefit:

Documenting outcomes is important in order to demonstrate that at a minimum, performance in the bimodal condition is equivalent to or better than performance in the cochlear implant alone condition. There are many potential measures that may be employed.

Recommended Strategy: Word testing in quiet and sentence testing in quiet and in noise following the procedure outlined in the Minimum Speech Test Battery for Adults[60]. Age-appropriate measures should be utilized for younger children. If possible, evaluate in the CI-alone, HA-alone and Bimodal conditions. It should be noted that HA-alone performance may be very poor. On the contrary, if contralateral hearing could potentially contribute to speech perception performance, it is recommended that plugging and/or muffing that ear be considered to isolate the cochlear implant.

Frequency Lowering: If this is utilized, it may be helpful to also complete Ling six sound detection and discrimination/identification testing, particularly as it relates to /s/ and /S/.

Loudness: Consider aided soundfield thresholds for both the cochlear implant and the hearing aid. It should be emphasized that this is to be completed in addition to real ear verification. The purpose of utilizing this measure is to validate the detection levels of soft sounds and to compare minimum detection levels for soft inputs across the two devices. With a properly fitted cochlear implant, detection levels should be equivalent across the frequency range. With the hearing aid, detection levels will depend on the degree of hearing loss and hearing aid fitting. For example, high frequency thresholds are expected to be poor with a restricted bandwidth fitting. On the other hand, high frequency thresholds may be slightly better with frequency lowering versus wideband fitting (see Davidson et al., 2015). If the outcomes are not as expected, further evaluation of the fitting is recommended.

Other Measures: Current assessment measures focusing on speech recognition with standard clinical set-ups may not be sensitive enough to show significant bimodal benefit. If time permits and these measures are available, it may be worthwhile to consider the following:

- Speech perception testing with a multiple loudspeaker array (e.g. R-Space)
- Speech perception testing in reverberation[61]
- Sound localization
- Music Perception
- Speaker Recognition
- Emotion Recognition
- Subjective Questionnaires (e.g. Speech, Spatial, and Qualities of Hearing questionnaire, SSQ)

What if no bimodal benefit is seen or bimodal decrement is observed?:

- Contact the CI audiologist to re-evaluate cochlear implant settings.
- Consider candidacy for bilateral cochlear implants.
- More extensive testing (e.g. for loudness balancing) may be necessary.
- More time may be needed to adapt to the bimodal signal[62,63] and/or bimodal fitting strategy (e.g. patient used to wideband fitting is trying frequency lowering for the first time). Also, consider if aural rehabilitation would be beneficial if this is not already in place[62].
- Reiss et al. (2014)[64] suggested that some bimodal users may experience significant difficulties with binaural spectral integration and are unable to resolve pitch mismatches perceived in the two ears. Alternative fitting strategies such as minimal-overlapping fitting[65,66] could be explored. Laria et al. (2014)[67] presented a case example wherein improvement was observed when the frequency range of the cochlear implant did not overlap with that of the hearing aid. It should be noted that current hybrid fitting protocols recommend some overlap between acoustic and electric hearing[68,69]. If this approach is appropriate for a particular bimodal patient, the audiologist may have to experiment to determine the edge frequency for acoustic and electric hearing that results in the best outcomes.
- Some recipients demonstrate bimodal decrement[11,58]. This is typically the exception, however, and not the rule.

Concluding Remarks

Improvements in cochlear implant technology and outcomes have resulted in expanded candidacy criteria. As a result, more implant recipients present with significant residual hearing and bimodal stimulation should be considered in order to provide access to bilateral, binaural & complementary acoustic cues. At minimum, the hearing aid should be fit to target and verified using real ear measurements. Additional benefits may be obtained by further optimization of the hearing aid fitting. Optimization can include consideration of alternative frequency response settings and/or loudness balancing. Due to the inherent variability in the cochlear implant population, the approach that provides the most benefit will vary from patient to patient. Outcomes assessment is important in individualizing the hearing aid fitting approach.

Case Studies:

Help us spread knowledge on bimodal fittings by adding your own bimodal fitting data to this paper.
Send patient case description to Kamilla Angelo, PhD, kian@oticon.com.

- Patient 1 is an 88-year-old male with a long-standing progressive hearing loss.

- Patient 2 is a 57-year-old female with bilateral progressive hearing loss due to enlarged vestibular aqueducts.

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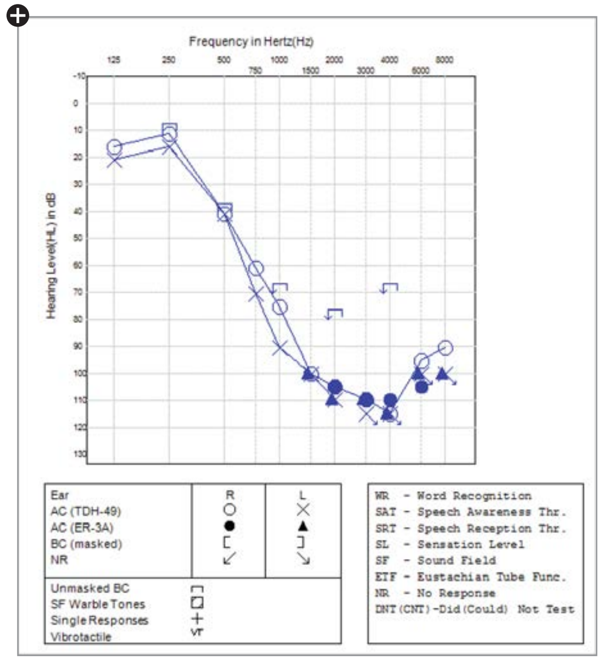
Case Studies: Patient 1

Adult Case Study: Patient 1 is an 88-year-old male with a long-standing progressive hearing loss. He has a history of occupational and military noise exposure without the use of hearing protection. At the time he went through the cochlear implant candidacy process, he had normal hearing at 125-250 Hz steeply sloping to a profound sensorineural hearing loss in the higher frequencies (See Figure 1). He had been utilizing hearing aids for over 20 years. He met the candidacy criteria for cochlear implantation and received a cochlear implant on his left ear.

Figure 1. Pre-implant audiogram for Patient 1.



Patient 1 continues to utilize a hearing aid in the non-implanted ear. This currently utilized hearing aid has frequency lowering (transposition) enabled to maximize high frequency audibility. The patient has indicated a preference for frequency lowering versus standard fitting. Probe microphone measurements indicate audibility up to about 1000 Hz (Figure 2). Using the Frequency Lowering Fitting Assistant (Figure 3), best performance was predicted using a start frequency (the first frequency that will be transposed) of 1600 Hz and "Expanded Mode" (transposition of 5 frequency bands versus 3 bands in "Basic Mode"). Gain for transposed sound is set at a default of 0.

Figure 2. Speech Map showing the probe microphone real ear measurement for Patient 1's Hearing Aid. Test 1 (green) shows results for standard wideband fitting while Test 4 (orange) shows results for frequency lowering.

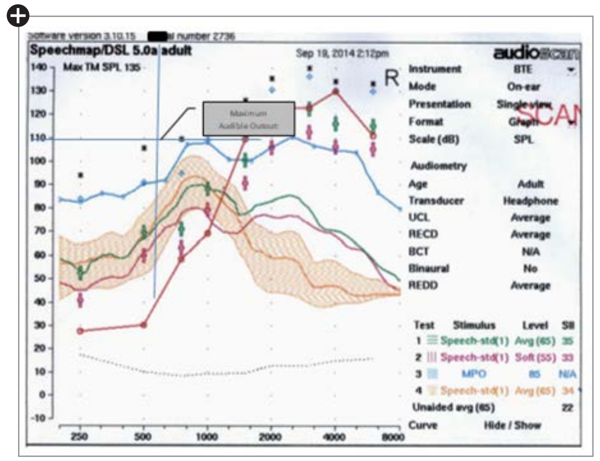
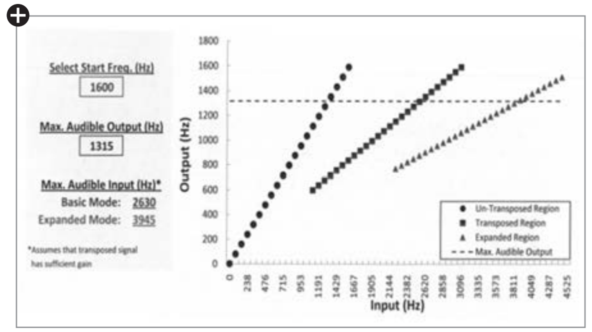


Figure 3. Settings provided by the Frequency Lowering Fitting Assistant.

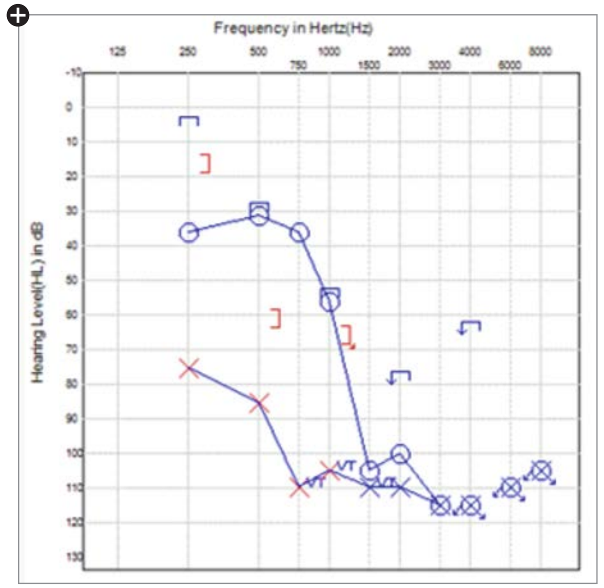


Patient 1 has had his implant for about a year and speech perception performance is shown in Table 1. Results indicate improvement over pre-implant performance and best performance in the bimodal condition. The patient is pleased with his current hearing.

TEST	Pre-Implant Score for Left Hearing Aid	Pre-Implant Score for Both Hearing Aids	Score with the Right Hearing Aid Alone	Score with Cochlear Implant Alone	Score in the Bimodal Condition
CNC Test -Words Correct -Phonemes Correct	12% 31%	Did not Test	24% 44%	40% 53%	40% 71%
HINT Sentences -Words Correct in Quiet	26%	62%	43%	57%	92%
AZ Bio Sentences -Words Correct in Quiet	Did not Test	32%	Did not Test	27%	67%

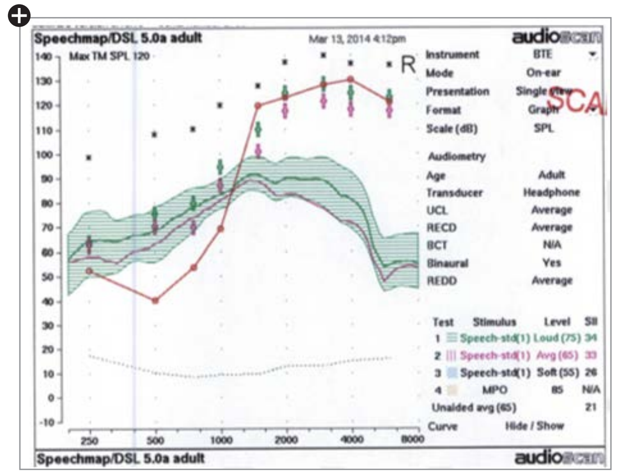
Case Studies: Patient 2

Patient 2 is a 57-year-old female with bilateral progressive hearing loss due to enlarged vestibular aqueducts. At the time she went through the cochlear implant candidacy process she had a mild sloping to profound hearing loss in the right ear and a severe to profound loss in the left ear. She met the candidacy criteria for cochlear implantation and received an implant in her left ear. She has had her device for approximately a year and a half.



Patient 2 continued utilizing her hearing aid following cochlear implantation. Her hearing aid is fitted to match adult DSL5.0 targets for as wide a bandwidth as possible given her steeply sloping loss. No frequency lowering is enabled even though it is available in her instrument because NFC will not improve audibility since MAF is 1500 Hz and 1500 Hz is the lowest start frequency available.

Due to binaural loudness summation, the patient requested a slight gain decrease. Probe microphone real ear measurement results are shown below.



Speech perception test results are shown in Table 2. Results indicate significant improvement in scores over pre-implant performance. Performance in the bimodal condition is similar to or slightly improved over performance with the cochlear implant alone. The patient is satisfied with her current hearing.

TEST	Pre-Implant Score for Left Hearing Aid	Pre-Implant Score for Both Hearing Aids	Score with the Right Hearing Aid Alone	Score with Cochlear Implant Alone	Score in the Bimodal Condition
CNC Test -Words Correct -Phonemes Correct	Did not Test	38% 80%	Did not Test	80% 91%	85% 95%
HINT Sentences -Words Correct in Quiet	32%	51%	58%	90%	98%
AZ Bio Sentences -Words Correct in Quiet -Words Correct in Noise	Did not Test	26% Did not Test	Did not Test	90% 66%	98% 76%

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