

## Maximizing the Potential of Severe Hearing Loss

### Final Thoughts

Our understanding of the normal auditory system is quite detailed. However, as we move into a consideration of the effects of sensorineural hearing loss, our knowledge base becomes thinner. One of the reasons is that the normal auditory system is not a simple unidirectional, stimulus-response sensory system. There are a wide variety of complex, inter-dependent functions designed to sharpen perception that include both afferent and efferent activities, nonlinear amplitude growth, frequency sharpening, cross-frequency inhibition, cognitive sorting, suppression & selection, etc. The auditory system is just that – a system. That system is composed of not just two encoding end organs but also the

brain that puts it all together. Like all sophisticated, adaptable systems, when failure occurs in one section, the system can re-organize itself. There is redundancy built in along with recovery and re-assignment of function. Although these patients may not have used their hearing as much as possible for many years due to limits in hearing aid technology, it is clear that the use of amplification that can exploit the remaining hearing to the fullest extent possible can be accepted. The role of the professional is to guide the patient through the process to use the capabilities of this new technology to the fullest extent possible.

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### Summary

For the patient with severe hearing loss, the most effective amplification strategy is the one that uses the remaining hearing to the fullest extent possible. These patients have the potential to use their hearing in ways that we may not have thought possible in the past, as long as they have access to the right technology. Epoq and Vigo RITE Power products combine a smooth, extended bandwidth with a dedicated compression approach to ensure that the patients with the greatest hearing losses can communicate as effectively as possible. Further, the wireless capabilities available in the Epoq products bring connectivity to the patients who need it the most. The reactions from patients reflect improvements in sound perception that go beyond just simply hearing more – patients feel a more natural connection to the sound environment. The Oticon RITE Power products have fundamentally changed what we can expect from patients with severe hearing loss and, most importantly, what they can expect from amplification.

In all hearing aid fittings, the goal is to try to get the most from the remaining hearing of the patient. This goal is brought into particular focus when the task is to fit a patient with severe hearing loss. As the hearing loss becomes more significant, all aspects of auditory function become at risk. For these patients, the question becomes: what is the true remaining capacity of the auditory system with severe hearing loss? The simple reality is that the capability of the impaired auditory system is dependent on the quality of the amplification system that is fit. Our traditional understanding as to what we can get out of the impaired auditory system has been tied to developments in hearing aid technology. As technology has improved, our expectations about what patients could do have increased proportionally.

The frontier of auditory capacity has been pushed forward with the release of the Epoq and Vigo RITE Power products. By providing a smoother response at higher frequencies than

ever before, increased gain for softer inputs without feedback and (in Epoq XW) a binaurally coordinated compression system that preserves natural inter-aural intensity differences, we are seeing patients with severe hearing loss use their auditory systems in ways most did not think possible.

In this paper, we will describe the specifics of the technologies implemented in the new RITE Power products from Oticon and relate those advances to what we know about patients with severe hearing loss. Oticon's long history of producing first rate solutions for these patients forms a backdrop for the new solutions that we have created. The initial success of the new RITE Power products provides testimony to our ability to expand the expectations that professionals should have about what patients with the greatest amounts of hearing loss can do with their remaining hearing. It is not about how much they have lost. It is all about getting the most from what remains.

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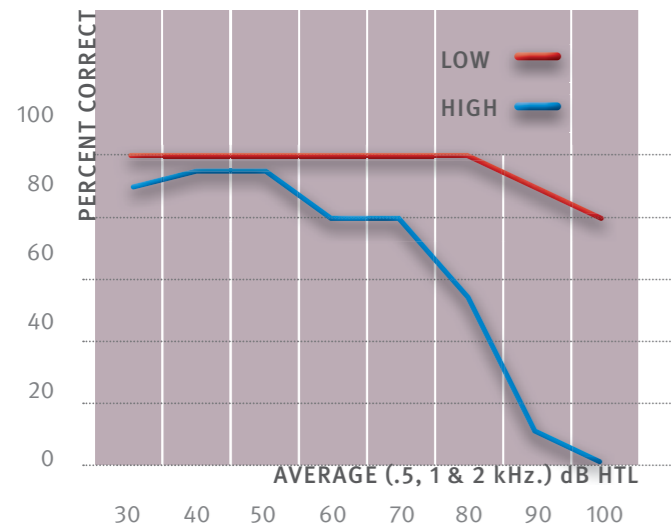


Figure 1: The maximum (red) and minimum (blue) word recognition scores for a large group of patients as a function of average hearing loss, based on the data presented by Lamore et al. (1990).

**What do we know about severe hearing loss?**

■ **Every Hearing Loss is Different:** This statement applies to all patients, of course. However, the physiological nature of hearing loss becomes more varied as thresholds get worse. Severe hearing loss is typified not just by the outer hair cell loss that is present in mild to moderate losses, but also various amounts of inner hair cell loss, ossification, neural cell death, membrane disruptions, metabolic changes, etc. The patient’s thresholds will not give a full picture of the integrity of the remaining hearing. As discussed by Boothroyd (1993), the ability to process complex auditory signals will vary significantly within the population of those with severe hearing loss. A good example of this fact is shown in *Figure 1*, based on the data of Lamore, Verweij & Brocaar (1990). The maximum and minimum word recognition score in quiet is shown as a function of average hearing loss for a large group of patients. Above an average hearing loss of 70 dB HL, the range of ability to recognize speech in quiet expands remarkably.

■ **Less Hearing to Work With (usually):** The common model of sensorineural hearing loss that describes the effect on loudness perception of hair cell loss predicts a significantly reduced dynamic range in the presence of severe hearing loss. Whereas the typical patient with a mild-to-moderate loss will have 50 dB or more of residual dynamic range, there will be far less distance from threshold to discomfort in many patients with severe hearing loss. However, when other physiological changes have occurred, loudness predictions may not be accurate on an individual basis. Some patients with severe hearing loss may have only 20 dB of range to work with but other may have a much higher upper limit of acceptable loudness.

■ **A Need to Hear:** Unlike patients with lesser degrees of hearing loss, patients with severe or profound loss may be focused on obtaining sufficient auditory stimulation. They have a limited amount of hearing and they may want to make sure that hearing is being used. Simple sound awareness and a connection to the environment may be limited. Hearing aids act to keep them connected to the world around them. Importantly, the patient’s hearing aid history may become an important factor in a new fitting. These patients will be quite attuned to the sound of their current hearing aids and are quick to compare any new technology to what they are used to hearing. Quite simply, they may have firm opinions as to how sound should “sound”.

**What is special about the Oticon RITE Power products?**

For patients with longstanding severe or profound hearing losses who otherwise do not receive cochlear implantation, advanced technology can offer new possibilities that they may not have experienced in the past. If these patients were fit originally with hearing aids 5, 10, 20 or more years ago, they may have only experienced power, linear amplification. Early attempts to use non-linear amplification with severe hearing loss met with limited success (e.g., Boothroyd et al., 1988; DeGennaro et al., 1986). However, with a better understanding of how to create non-linear solutions along with adjustments to environmentally adaptive circuits such as noise reduction and automatic directionality, the hearing aid industry has created effective advanced solutions for these patients (e.g., Souza & Bishop, 1999).

Oticon has been a leader in creating multi-channel, nonlinear solutions for patients with the greatest degrees of hearing loss. Products such as Adapto Power, Syncro Power and Sumo DM have demonstrated our ability to successfully provide these patients with the long-sought benefits of nonlinear amplification (Flynn, Davis & Pogash, 2004; Flynn, Pogash & Esser-Leyding, 2006). With the release of the Epoq and Vigo RITE Powers, we have again pushed the expectation of what is possible from technology for these patients to the next level. There are several important achievements in these products that contribute to successful patient acceptance:

**The Rise Platform:** We have successfully adapted the Rise digital platform that forms the basis of the Epoq and Vigo products to provide the signal processing, gain and output needed for severe hearing loss patients. Not only does this platform bring along the obvious benefits of broader bandwidth and wireless connection, the high level of signal integrity in this new electronic processor provides these patients with amplified sound that as closely as possible represent the true natural state of the incoming speech signal. Since these patients have an increased level of internal distortion created by their impaired system, it crucial to provide them with the cleanest signal processing possible.

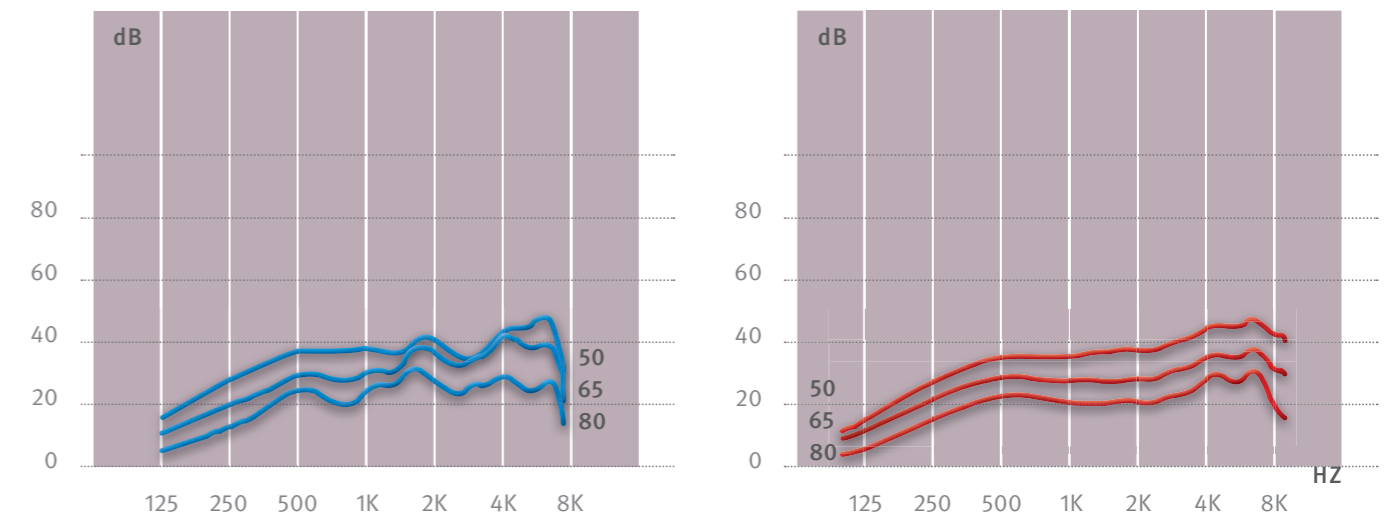


Figure 2: Insertion gain response for 50, 65 and 80 dB SPL inputs for the Syncro Power BTE on the left and the Epoq RITE Power on the right.

**The New RITE Power Receiver:** We have secured a state-of-the-art receiver specifically suited for the RITE hearing aid design. This receiver allows us to provide the patient with the full bandwidth created by the RISE platform but with a smooth response and clean, undistorted output levels never seen before in a power product. Again, our goal with this product is to allow the patients to get the very most from their remaining hearing and this new receiver is precisely what is needed to provide the patients with access to signals across the full input range from soft through loud and across the broadest bandwidth possible.

*Figure 2* provides the estimated insertion levels generated by the Epoq RITE Power and by the Syncro Power BTE when similar levels of high frequency gain were attempted to be

generated. Notice the difference in the smoothness of the response when trying to maximize the response in the highs. Syncro Power BTE was a very successful solution for severe hearing loss when it was introduced, but the newer technologies that we have now assembled allow even better opportunity for the patient to use what hearing remains.

*Figure 3* provides the estimated insertion gain levels generated by the Epoq RITE Power and by the Sumo DM super power BTE when trying to maximize high frequency gain for a sloping severe-to-profound hearing loss. In this case, it is clear that the Sumo DM can create higher maximum gain levels, especially in the lower frequencies. However, there are inherent peaks in the response created by that generation of receiver technology. For some patients with this much hearing loss, that sort of

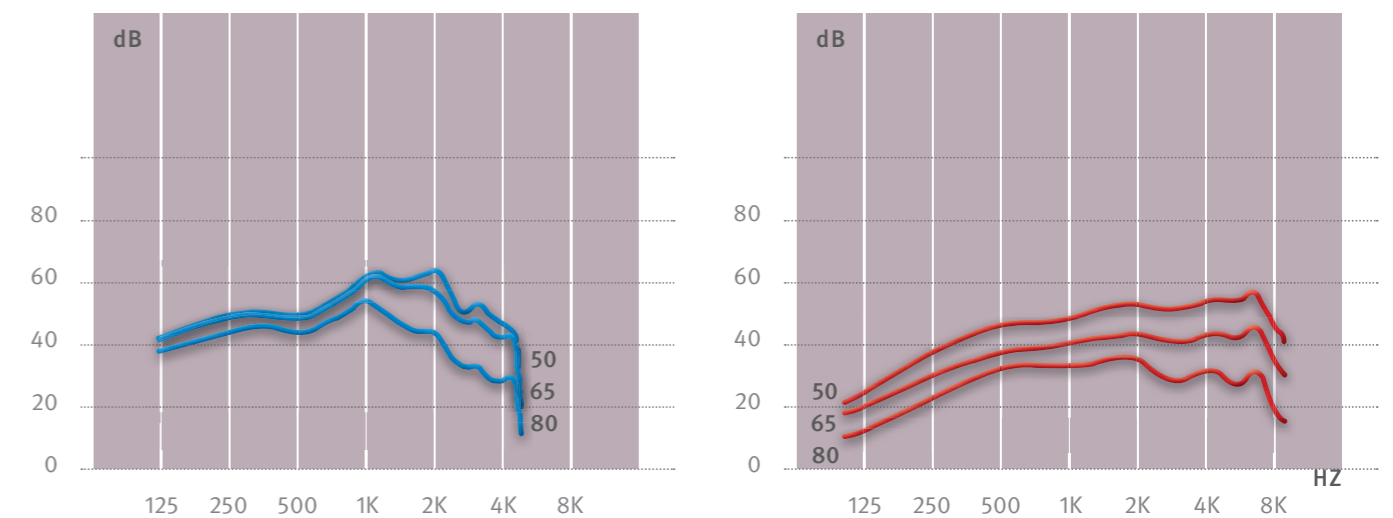


Figure 3: Insertion gain response for 50, 65 and 80 dB SPL inputs for the Sumo DM BTE on the left and the Epoq RITE Power on the right.

response is needed to provide a sense of loudness or fullness to the signal. However, some patients with this much hearing loss and better residual auditory resolution have shown to respond better to the smoother, broader response possible in the Epoq and Vigo RITE Powers.

**Improved Feedback Cancellation:** In the Spring of 2008, we introduced an important improvement to our Dynamic Feedback Cancellation system. The improvements in DFC2 allowed the hearing aid to operate closer to feedback threshold without the instability and distortion that is typical of older feedback cancellation approaches. The processing speed and capacity of the Rise platform allows for feedback to be identified not just on the audible signal but even before as the response of the device starts to become unstable. This instability is the trigger for the DFC2 to target this new feedback component that is starting to form.

Although this improvement is important for all users, especially with so many fittings being open these days, the benefit is particularly important for patients with severe losses. They will call for the greatest gain levels well into the higher frequencies as they strive to experience the advantage of improved audibility for soft and moderate sounds that is the calling card of WDRC processing. The improved DFC2 was essential for us to get the most from the full bandwidth and greater gain levels of the Rise platform and new power receiver.

**Power Adjustments:** Although there is a strong possibility that a patient with severe or profound loss will benefit from the improved audibility provided by WDRC amplification, the application of gain and compression must reflect the specific needs of those with this much hearing loss. These patients tend to focus on a full sound quality, again reflecting a desire for auditory stimulation. Our strategy to achieve this effect is to focus on the “mids & mids”: mid frequencies and mid-level (conversational speech) inputs. With a power linear response, the patient will tend to use lower frequency and louder inputs as a guide to setting the device. With the application of WDRC, the mids & mids can become the focus of the sound of the devices. For both the Voice Aligned Compression (VAC) rationale in Epoq RITE Power and the NAL-NL1 response in Vigo RITE Power, for severe hearing loss the focus of the response tends to be in the region around 2 KHz. The patient will still have access to sound above 2 kHz., but the focus of the response is more mid-frequency. The patient receives the benefit of the extended bandwidth but with a careful mix of enough mid-frequency response for the hearing aid to sound familiar enough.

**Modern Size & Styling:** All patients want their hearing aids to look as good as possible. Design has always been hampered in the development of power hearing aids due to the need for larger batteries, casing and receivers and traditional, full-shell earmolds. It is a great achievement for patients with severe

hearing loss to be able to offer them a true power instrument in a modern case style and cosmetically improved RITE coupling, all driven by a 312 battery. The patients who are switching from older instruments to Epoq and Vigo RITE power have likely been using much larger, traditionally designed devices driven by either a 13 or, in many cases, a 675 sized battery. The opportunity to have a dramatic cosmetic upgrade has been well appreciated by the patients fit so far.

**Connectivity:** Of all patients, those with severe hearing loss have the most struggles with audio signals arriving from devices such as cell phone, landline phones, televisions, etc. The Epoq RITE Powers now offer the liberation of connectivity in hearing instruments with the gain and output required by these users. Although the hearing aids by themselves offer excellent access to important speech information, there are always situations – cell phone use especially – that will continue to vex the user. The presence of the digital magnetic transmitter and receiver in each Epoq RITE Power along with the use of the Streamer gateway device allow for the reception of Bluetooth transmissions from the user’s cell phone. The Streamer device can also be used to deliver any audio signal transmitted via Bluetooth or, for that matter, hard wired to the Streamer. Excellent technical solutions are now available to get important signals from televisions, landline phones and a host of other electronic devices into the Streamer. Patient with severe hearing loss often feel that they simply cannot make easy use of such prevalent consumer electronic devices. The connectivity in Epoq RITE Power changes all of that.

### Using – Not Abandoning – Hearing

There is a push currently to use frequency lowering or transposition techniques any time the patient has more than a moderate hearing loss in the higher frequencies. Some have gone so far as to suggest that frequency transposition is appropriate for those with even less hearing loss (e.g., Alexander et al., 2008). These radical suggestions appear to reflect an attitude that if a technology has been developed, it should be used even if it does not make audiological sense. There is no doubt that there is a place for effective frequency lowering or transposition approaches, **but only when it is absolutely clear that the patient cannot make use of the hearing in the higher frequencies in a natural manner.**

As pointed out by Kuk et al. (2008), frequency lowering or transposition should be:

“...used only when there are no better alternatives. If a frequency region can be amplified by conventional means, one should amplify that region instead of using transposition to access the same information.”

What little research that there is on the effects of frequency altering approaches have typically compared to direct amplification approaches using hearing aids with little or no

useable insertion gain in the higher frequencies (e.g., Alexander et al., 2008). The application of a frequency altering strategy without first thoroughly examining if the patient can make use of cleanly amplified high frequency information is simply not justified. It is understandable that if a manufacturer cannot provide significant high frequency gain without feeding back or distorting, then there would be a push to move information to a lower frequency. However, the technology in the Epoq and Vigo RITE Power products has clearly been demonstrated to be able to provide quite sufficient audibility even for softer input in the higher frequencies without concerns of feedback or distortion. Frequency altering technologies are not the prudent course of action if the patient has not had the opportunity to be fit with power products that can effectively stimulate the higher frequencies in a direct, natural manner.

### Reaction from Patients

The reaction from patients who have been fit with the Epoq and Vigo RITE power products reflects the value of improved bandwidth and access to softer signals. Additionally, they have responded markedly to the design and connectivity features of the product. Again, these patients usually have a long history of hearing aid use and so they know what works well and where their needs are not being met. The emergence of the Oticon RITE Power devices reflects not just new audiological benefits but advantages that fundamentally affect these patients’ lives.

Along with our traditional product verification research, we have also been carefully tracking the spontaneous reactions from patients to these fittings. Traditional audiometric approaches to measuring benefit are essential, yet they may not capture all aspects of the impact of these devices on the lives of patients. Hearing these patients describe the devices in their own words provides important validation of the efforts that went into creating these new solutions. We have noticed three important trends in the spontaneous reactions from patients.

**1: An Expanded Listening Environment:** Of course patients do not use terms such as “expanded bandwidth”, “smooth, high-frequency response” and “improved audibility for soft to moderate sounds”. However, they certainly appear to hear the effects. The patients are using terms such as “clarity”, “distinctness” and “crisp & strong”. Further, they are reporting that they feel that they can hear more of what is going on in a setting. They are not limited to just a face-to-face conversation with one person, but feel they have a greater appreciation for all of the sound sources in their environment. For example, one 70 year man had been using hearing aids for over 40 years and he was at a point where he “could only converse at close range in a quiet environment”. He now feels that he can negotiate larger group situations effectively. A woman in her late 50’s with a sloping severe hearing loss who had been wearing devices since she was a child reported that it was her family who noticed the biggest differences. She was hearing

conversations from room to room or with her back turned, without the need for visual cues. Importantly, her family told her that she now “laughed at the right times” during casual family conversations. This comment highlights that communication is not just about transferring information. It is also about the bonding that takes place from person to person. The grown son of own older man with severe hearing loss commented about how his father was behaving much more appropriately in social situations. The patient did not have as much need to dominate or control conversations (as has been classically observed about some with severe and profound losses). Rather, he has become better able to effortlessly and seamlessly interact in these group conversations.

There are many comments about hearing the ambience of an environment, which engenders a feeling of connection. These comments call to mind Ramsdell’s (1978) description of the primitive level of hearing – that vital but often under-appreciated characteristic of our hearing that allows us to feel part of our surroundings.

Interestingly, access to new information, especially higher frequency and softer sounds, may catch the user off guard. In one case, a man who had been using hearing aids for 25 years was delighted with his new Epoq RITE Powers, but made comments about hearing and having to get used to all the little sounds in his environment. Although this is a comment that is usually made by a first time user, it is clear that this very experienced user simply had not been provided with this sort of audibility before.

In another case, a 53 year old woman with Usher Syndrome who had a severe hearing loss noticed a significant improvement in speech clarity compared to a more traditional power fitting. Her husband noted her improved confidence and willingness to place herself in group situations. This patient had thresholds between 1 and 4 kHz in the range from 70 to 90 dB HL. In this frequency region, there happens to be a lot of visual information that all hearing impaired listeners will naturally use. However, given her visual impairment, she is completely dependent on auditory cues for high frequency consonant information. It is not surprising that the improved audibility in the region afforded by Epoq RITE Powers was so noticeable for her and her husband.

**2: Connectivity:** The simple truth is that if a device makes sound, persons with severe hearing loss likely have difficulties hearing it. The possibility of connectivity created a natural interest in these products by those with the greatest hearing losses. Many professionals have decided that the connectivity option alone is a reason to get into contact with formerly fit severe hearing loss patients and have them come back in for a demonstration. The benefits of improved connectivity have been easily appreciated. Nearly all patients that we have received reports from who have tried using Epoq RITE Power with a Streamer have reported markedly

improved performance on the phone. Many are also using the Streamer and the associates TV solution to be able to enjoy television with other family members in a way that has not been possible before.

In one case, a 37 year old man with a U-shaped severe hearing loss that had been progressive since age seven needed help on the phone. He owns an insurance company and phone use is absolutely essential in that line of work. Given his hearing loss, of course phone use has been a long standing challenge. Now, with the combination of Epoq RITE Powers, Streamer and a Bluetooth enabled office phone, he can successfully communicate again over the phone. Similarly, there is the case of a 45 year old physician with a progressive loss that is now severe where phone use was not a nice-to-have feature, but rather, essential for this person to continue to be successful in his career.

**3: Cosmetics:** The smaller size and modern case and RITE design have not been lost on these patients. We sometimes think that because a patient has been hearing impaired so long, that they do not concern themselves with the cosmetics of a device and only care about what works for them. This is a somewhat paternalistic viewpoint. These patients have every right to have access to the best looking devices possible.

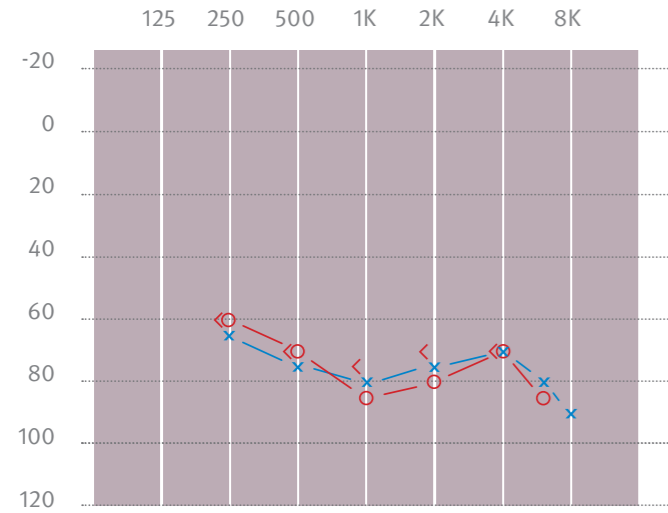


Figure 4: Audiogram for patient BG.

In one case, a 31 year old man with a sloping severe hearing loss in his only hearing ear was concerned with how his old ITE looked as he was preparing to marry. The ability to move to a smaller, stylish mini-BTE with RITE coupling decreased his self-consciousness over the looks of his device. That improvement in confidence along with his use of the Streamer for cell phone and music listening has moved him into a new, modern era of amplification.

In fact, we typically assume that patients with long-standing severe hearing loss are always experienced users. As you know, many progressive, adult onset hearing losses that end up as severe start as a mild loss. In dramatic cases, some patients will resist getting amplification even as the hearing loss progresses over the years into the severe category. One phenomenon that has occurred is that some patients who had been resisting the idea of using hearing aids because of all of the classic reasons, including cosmetics, have now been willing to try hearing aids because the size and style are now far more acceptable.

**The Case of BG:** BG is a 55 year old woman who case highlights benefits in all three of these areas. She has a progressive, familial sensorineural hearing loss. Currently, her thresholds are symmetrical and range between 70 and 85 dB HL from 500 through 6000 Hz (see Figure 4). She has a 28 year history of hearing aid use. She used custom products for many years, but a little more than a year ago her loss had progressed enough that standard devices could no longer give her the audibility she felt she needed. At that time, she was fit with Sumo DM BTEs bilaterally. The Sumos made an immediate difference for her, as her custom devices up to that point simply were not powerful enough. Over the course of a year's use with Sumos, she felt that she still thought that she could perform better. She also had serious issues with phone use.

When the Epoq RITE Powers first became available, she was fit. After several weeks of use, she returned for comparative testing of the two sets of devices. Figure 5 shows the insertion achieved at user setting for both the Sumo DM and the Epoq RITE Power. Insertion gain values are shown for 45, 65 and 80 dB SPL inputs. This data is for the left ear, but the results for the right were similar. The Sumo was fit with fully occluding soft shell molds

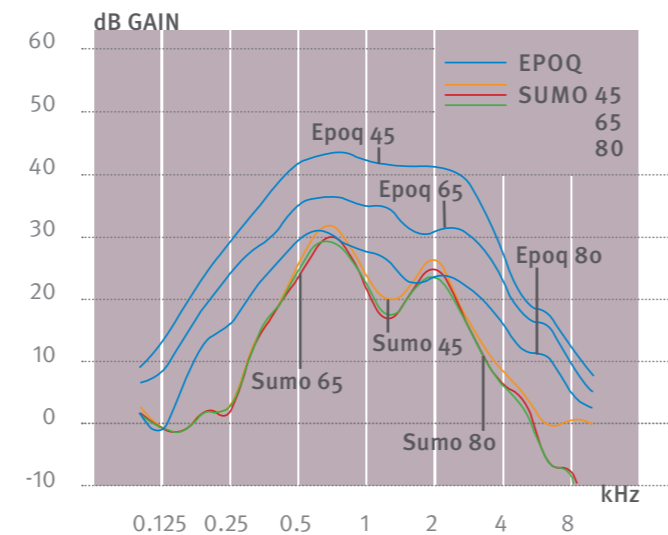


Figure 5: Real-ear Insertion Gain values for 45, 65 and 80 dB SPL inputs for Sumo DM and Epoq RITE Power for patient BG.

and the Epoq RITE Powers were fit with closed Power Molds (custom fit hard shell molds approximately the size of an ITC).

Notice that the insertion gain for the Sumo was essentially the same for all input settings. That was based on BG's initial reaction the Sumos in which the Classic Identity was used due to the patient's preference for a linear signal. The audiologist who fit BG attempted to move her to a non-linear setting in order to have better access to softer sounds, but BG could not adapt to a compressed signal through the Sumo devices. Also, the patient controlled the gain level and reported that the volume control setting used in this measurement represented her preferred setting across a range of environments. However, she did find herself manipulating the volume control wheel often when changing environments in search of an elusive better response.

Quite interestingly, the insertion gain settings for the Epoq matched the peaks in the Sumo response for loud inputs. However, two very important differences are clear beyond that point: significantly greater gain is accepted and available for the 45 and 65 dB input levels and the response is much broader and smoother. For soft to moderate speech inputs, up to 20 dB greater insertion gain is available out to 8 kHz. Also notice that there is more low frequency gain available at all input levels. Although the Sumo has the potential for greater gain and output, the patient chose not to use the full potential. Preferred use gain setting apparently was driven by the peaks in the insertion gain response in louder environments. The acceptable non-linearity in the Epoqs in combination with the broader, smoother response provided clearly more access to important speech information.

In order to objectively verify the effect on speech understanding, word recognition in noise testing was performed in the soundfield. The NU-6 50-item word lists were presented in a background of speech babble, with the speech presented from 0 degrees and the competition from 180 degrees azimuth. The presentation level of the speech was 60 dB HL with the noise at 50 dB HL (+10 dB S/N). BG scored 54% with the bilateral Sumo fitting and 84% with the binaural Epoq RITE Power fitting. Analysis of her errors provided clear evidence of the improved high frequency consonant information available via the Epoq devices. Here are examples of the errors she made while wearing the Sumos: hey for hate, wife for white, Keith for keep, low for loaf, cheat for chief, dike for pike, Tom for calm, so for soap. All of these errors represent a misperception of high frequency consonants. With the Epoqs, of course there were less errors overall, but also the errors did not indicate such a clear lack of good high frequency response. Examples were: luck for lot, Jane for jar, mope for moon.

She was interviewed along with her husband to determine the specific things that had been noticed when the fitting was changed. The following observations were reported and described in detail:

- Ease of phone and television use due to the use of the Streamer
- Being able to hear softer sounds (such as birds and ticking clocks) or sounds from a distance (microwave and dryer times)
- Being able to carry on conversations without seeing the person and being able to communicate room-to-room
- Needing to have the talker repeat far less often (a point especially emphasized and appreciated by her husband)
- Not needing to make volume control adjustments when moving from environment to environment

It is clear when reviewing the real ear, speech testing and subjective comments that the success that this patient experienced with the upgraded fitting was representative of the range of benefits reported by users overall.

**What does it take to get the most from these fittings?**

The strategy that guides the fitting of modern advanced technology amplification to a patient with this much hearing loss is *to challenge the auditory system with more information than has been available in the past*. We accomplish this by providing better gain across a broader bandwidth than they have experienced before. As noted above, these patients may have firm ideas as to what they expect from the sound of hearing aids. They typically have a long history of amplification and are highly dependent on their hearing aids. Changes in the sound processing may not be immediately appreciated and quick rejection is often looming. However, as more new information is provided and as the patient experiences improved communication functioning, the value of the new amplification approach will become evident.

It is also important to explore the patient's hearing. As indicated above, the professional should expect greater sound processing variability from patient to patient than may be present in the population of more typical hearing aid users. Prescribed responses from Genie should be viewed as only a starting place. The audiogram does not provide a complete picture of how the ears are working. Some of these patients may need a less aggressive identity in order to extract the most information from the compressed signal. Others will have enough remaining auditory resolution to handle a highly compressed signal and may even be able to handle faster time constants, and such a more aggressive Identity may make sense. Also, the Genie fitting software will predict a the top end of the dynamic range based on the mean relationship between hearing loss and UCL. Since these patients are sensitive to signals becoming overly compressed, individual assessment of the UCL may allow for the operating output range of the device to be increased so that the amount of compression needed to map sounds into the dynamic range can be decreased. All of these possibilities are difficult to predict but can easily be evaluated through adjustments to flexible amplification.