Limitations of Conventional Hearing Aids

Examining Common Complaints and Issues that Can and Cannot Be Remedied

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KEYWORDS

• Hearing aids • Bone osseointegrated implants • Middle ear implants
• Acoustic feedback • Occlusion effect • Discomfort

KEY POINTS

- With modern hearing aids, clinicians can often reduce common hearing aid complaints, such as acoustic feedback and the occlusion effect and discomfort, without the need to recommend implantable devices.
- Reducing or eliminating the occlusion effect can make a hearing aid more susceptible to acoustic feedback and reducing acoustic feedback, in turn, may cause the occlusion effect.
- For patients with severe hearing loss or other unique circumstances that make conventional hearing aids difficult or uncomfortable to use, turning to middle ear implants or osseointegrated implants can be appropriate.

Conventional hearing aids (CHAs) undergo constant improvement and technological and cosmetic modification, and work well for most patients with hearing loss. However, there are a number of reasons CHAs may not work well for a particular patient and why implantable devices may be preferable for them. A patient's dissatisfaction with CHAs may be due to inadequate sound and/or speech amplification, visibility/cosmesis, and/or the inability to consistently wear the CHA owing to chronic otitis externa or middle ear disease. As an alternative to CHAs, osseointegrated implants (OI), initially approved by the US Food and Drug Administration in 1996 and subsequently expanded as approved for single-sided deafness (SSD),[1] or middle ear implants (MEIs), approved by the US Food and Drug Administration in 2001, help patients with conductive, mixed, or sensorineural hearing loss who have tried CHAs

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with limited success or with dissatisfaction.[2] Some benefits of MEIs or OIs over CHAs are undeniable, such as the ability to be worn 24 hours per day (whereas CHAs must be removed for sleep), near or complete invisibility, and efficacy in atretic or other malformed ears. Additionally, OIs and MEIs are also often cited as superior to CHAs for their ability to eliminate feedback and the consequences of occlusion, and for solving the problem of a patient who frequently suffers from CHA-related ear infections or otherwise finds their CHA too uncomfortable to wear consistently.[1] This article explores what can be done clinically for CHA users suffering from excessive feedback, the occlusion effect, frequent ear infections, or CHA discomfort to optimize their use of CHA, and in what circumstances implantable devices are be a superior option.

The increased use of implantable devices in recent years suggests that, at least in some cases, CHA users are dissatisfied. MEIs are expensive relative to CHAs and even though OIs may be more affordable, because they are often covered through insurance, both types of implantable devices include an invasive procedure. Significant advances in CHA technology have, however, increased patient satisfaction, making the traditional complaints about CHA less common. MarkeTrak 9, a 2015 survey, found that overall CHA satisfaction increased from 74% in 2008 to 81% in 2015. Patient satisfaction was even higher for CHAs purchased in the last year at 91%. In 2015, more than one-half of repeat CHA buyers (51%) considered their CHAs to be much better than their previous CHAs, and 34% considered them somewhat better.[3] Technological advances since 2015 in CHAs, including improvements in signal processing and new features (eg, Bluetooth and automatic programs), have likely only increased satisfaction levels.

Complaints of feedback and the occlusion effect, which used to be prevalent, can now be addressed for the majority of CHA users without the need for an implantable device. The advances made in signal processing, when paired with expert fitting and dispensing of CHAs, can eliminate the effects of feedback and occlusion for most patients. Other complaints (eg, infections and general discomfort) and restraints (eg, gain requirements) can also be addressed successfully for many CHA users because there are many types, styles, and materials available for use in CHAs. This article examines and evaluates the methods, from an audiologist's perspective, of reducing these common complaints in patients with a CHA. These methods are often able to significantly reduce or eliminate feedback, occlusion effect, and discomfort and provide sufficient gain. However, for some patients remedying these issues may not be possible because they come with tradeoffs that make implantable devices more desirable options for specific patients.

OCCLUSION EFFECT

CHA users may have complaints about the sound of their own voice. They may find that their voice sounds hollow or "boomy," and it may sound like they are in a barrel. These complaints, in addition to complaints of other self-produced sounds having a similarly unpleasant reverberation or echo (eg, chewing), are due to the occlusion effect. The occlusion effect occurs when self-produced sounds are transmitted simultaneously via air conduction and bone conduction. When the ear canal is open, as is the case for individuals without CHAs, the increased sound pressure leaks out. However, when a CHA or ear mold blocks the ear canal, the increased sound pressure is retained in the ear canal, causing the occlusion effect.[4]

The degree of low-frequency hearing loss often determines whether or not an individual struggles with the occlusion effect. Individuals with a 60 decibels hearing level hearing loss in the low frequencies should not be bothered by the occlusion effect.

Because these individuals require significant low-frequency gain from the CHA, the increased sound of their own voice from the occlusion effect is not noticeable or unpleasant when coupled with the amplification already being provided by the CHA. The occlusion effect, however, is particularly troublesome to those with less than a 50 decibels hearing level low-frequency hearing loss.[5]

Ineffective, But Often Used, Methods for Reducing the Occlusion Effect

There are 2 common, yet ineffective, methods used to manage the occlusion effect that may propagate, rather than alleviate, complaints: (1) the "get used to it" approach and (2) lowering the low-frequency gain. A patient suffering from the occlusion effect is often counseled to get used to the new sound of their own voice. When the sound of their own voice is altered by the occlusion effect, acclimating to the "boomy" or hollow quality is nearly impossible, because the occlusion effect may increase the level of low-frequency sounds, such as vowels, upward of 20 to 30 dB.[5] Asking a patient to acclimate to this level of change is unreasonable and could lead to reduced CHA use. The other flawed method in reducing the occlusion effect is to lower the low-frequency gain. Some CHA manufacturers even have an "occlusion manager" feature in their software designed specifically for this purpose. The increased low-frequency sound from the occlusion effect does not come from the low-frequency gain from the CHA; rather, it is created from the closed off ear canal. Decreasing low-frequency gain will not decrease complaints of the occlusion effect, but only increase complaints of CHA ineffectiveness.[6]

Effective Methods for Minimizing or Eliminating the Occlusion Effect

There are, however, 2 methods that a clinician can use to eliminate the occlusion effect in patients: (1) venting and (2) deep insertion. In addition, if those methods are not feasible for the reasons detailed elsewhere in this article, a clinician can also try to increase low-frequency gain to decrease (but not eliminate) the occlusion effect.

Venting is done by creating a space between the CHA or ear mold and the ear canal. Kuk and Keenan[6] determined that widening the vent diameter by 1 mm decreases the objective occlusion effect by 4 dB. To fully avoid the occlusion effect, a vent diameter may have to be up to 5 mm. A large vent diameter required to eliminate the occlusion effect may not always be possible owing to space limitations (ie, a small ear canal). Open ear canal fittings, using a receiver-in-the-canal (RIC) CHA, which are extremely popular today are, in essence, a very well-vented or large vented CHA. This style is recommended to eliminate the occlusion effect for patients where the hearing loss at 500 Hz is 20 decibels hearing level or less.[6]

Although effective at decreasing, and even eliminating, the occlusion effect, venting, including through the use of open ear canal fittings, may not be appropriate for all patients. Venting size is often limited for patients with a significant high-frequency loss, because greater amplification is needed to maximize audibility, which often results in unwanted whistling, known as audible feedback. Therefore, venting may not be an option when there is a mild or moderate low-frequency hearing loss that slopes to a severe high-frequency hearing loss.[7] Another potential problem associated with venting is that it creates an open ear canal, allowing natural sound into the ear that is not affected by the CHA's signal processing. If natural sound dominates the amplified sound, the benefits of noise reduction and directional microphones are decreased.[5]

Another method to eliminate the occlusion effect is through deeper CHA canal fittings. Killion and associates[7] found that fitting the CHA or ear mold deep into the bony portion of the ear canal, close to the ear drum, decreases the occlusion effect by increasing impedance at the ear drum. Impedance at the ear drum increases the

resonant frequency of the residual ear canal space and reduces the vibration of the ear canal.[7] Although they will relieve the occlusion effect, deep ear canal fittings have drawbacks in that they can be difficult for a clinician to fit and uncomfortable for a patient to wear. A deep ear canal fitting involves obtaining a deep ear mold impression. Some clinicians may be wary of obtaining a mold that must be close in proximity to the ear drum and the impression making process may cause patient discomfort. Deeply set CHA shells or ear molds are also often difficult to insert and remove. Finally, patients may find a deep fit uncomfortable, especially when worn for long periods of time.[5]

A way to lessen, but not eliminate, the undesirable consequences of the occlusion effect is to increase low-frequency gain. Although, as discussed elsewhere in this article, decreasing low-frequency gain is a method commonly touted for reducing the occlusion effect, increasing low-frequency gain is in fact the more effective approach. Added low-frequency gain allows the user to hear their own voice with amplified sound. This technique creates a better maintained consonant-to-vowel intensity ratio, which masks the annoyance of the occlusion effect and results in a more natural sound of one's own voice. Increasing low-frequency gain may have negative side effects, such as decreased sound quality and reduced ability to understand speech in situations where there is background noise.[6]

The skilled clinician must properly identify the occlusion effect and can then successfully decrease and even eliminate it. Through the use of venting, deeper canal fittings, or increasing low-frequency gain, clinicians can improve the quality of a patient's own voice to a satisfactory level, but should be wary that it may open up other problems such as feedback, discomfort, and CHA usage difficulty. Solving for the occlusion effect could also lead to decreased CHA functionality in the form of (1) less effective noise reduction, (2) reduced benefits of directional microphones, and (3) an overall decrease in sound quality.

Occlusion and Contralateral Routing of Signals

For traditional contralateral routing of signals (CROS) hearing aids, the user wears a microphone on the impaired ear, which is embedded into a behind-the-ear (BTE) or custom, in-the-ear (ITE), style CHA case. The microphone wirelessly transmits a signal to the hearing ear via a CHA. The CROS hearing aid is effective for providing 2-sided (but not true stereo) hearing, but the presence of a device in the better ear could lead to the occlusion effect. In those circumstances, an OI can be placed on the impaired side to pick up and then deliver sound directly to the hearing ear's cochlea via bone conduction, a process that avoids a device in the good ear and therefore presents no risk for occlusion.

Once they were introduced and approved, OIs were preferred over CROS hearing aids in the SSD population, in many cases owing to better performance and sound quality in noisy environments.[8–10] With improvement in CROS technology (eg, digital noise reduction and directional microphones), recent studies have shown that modern CROS hearing aids and OI users receive similar objective benefits from both devices.[11,12] Subjectively, Finbrow and colleagues[12] (2015) found that sound quality was superior in CROS hearing aids; 4 of their 8 participants preferred CROS hearing aids over OIs. Three preferred OIs based on nonsound quality factors, such as a preference for wearing one device instead of the 2 required in the CROS hearing aids and retention issues with the CROS domes. One participant did not have an overall preference because he found the sound quality of the CROS favorable, but preferred the OI for comfort.[13]

Although improvements in CROS devices might make CROS hearing aids preferable for many patients, allowing them to avoid the surgical procedure required for an OI, occlusion can be problematic for CROS users. To minimize the occlusion effect caused by the CHA worn on the hearing ear, the CHA can be well-vented (for an ITE-style CHA) or be an open ear piece (eg, dome) for RIC- or BTE-style CHAs. However, occlusion effect problems may persist for patients with narrow or curvy ear canals, where the vent size must be limited, or in instances where the CHA receiver itself may occupy a significant portion of the ear canal, as is sometimes the case for RIC-style CHAs. In addition, for SSD patients, if the CHA is too occluding, it can attenuate the natural sound entering the hearing ear. Should the occlusion effect be problematic for an SSD patient using, or trying, a CROS hearing aid, an OI may be an effective alternative.

FEEDBACK

Historically, feedback has been a major complaint associated with CHAs. In 2000, MarkeTrak VI found that only 44% of CHA users were satisfied with the whistling/feedback/buzzing of their CHAs.[13] This whistling, or high-frequency tonal sound emitted by CHAs, is known as acoustic feedback. Acoustic feedback occurs when the amplified sound of the CHA leaks out of the ear canal and is picked up by the microphone and then passed through the CHA again. Acoustic feedback is almost always present in CHAs, but is not always audible. Feedback will only be audible if the output of the receiver that reaches the microphone exceeds the original input level, which produces the whistling sound.[6]

Three Traditional Approaches to Reducing Feedback

To reduce or eliminate audible feedback, one approach is to simply reduce the gain at the problematic frequencies. Reducing the gain, however, will cause underamplification and decrease audibility.[6] A second approach to reduce feedback is decreasing the amount of sound leakage from the ear canal, which is accomplished by decreasing the vent size or creating a tighter fit of the CHA shell or ear mold. Decreasing the amount of sound leakage increases the attenuation of the feedback path and, accordingly, the amount of audible feedback. Decreasing sound leakage, however, also has its drawbacks. Decreasing the vent size, or eliminating the vent completely, may result in the occlusion effect, which, as discussed elsewhere in this article, is another problem for patients with a CHA. Decreasing sound leakage by creating a tighter fit of the CHA shell or ear mold and/or lengthening the canal can also lead to physical discomfort for patients.[14] A third approach to decreasing audible feedback is to pick a style of CHA that has a greater distance between the microphone and the receiver. For instance, completely-in-the-canal CHA have a short distance between the microphone and receiver, whereas RIC CHAs or larger ITE style CHAs (eg, half-shell or full-shell) have a greater distance. An individual with a significant hearing loss, needing high levels of gain, would require a greater distance between the microphone and receiver, such as provided by large ITE-style or RIC-style CHAs. However, if an individual is physically uncomfortable with such style and prefers a small ITE style (eg, a completely-in-the-canal CHA), it may result in reduced usage. Fortunately, RIC CHAs are extremely popular today, making up almost three-quarters of CHA sales, and also happen to be the preferred style when trying to minimize feedback.[15]

Modern Advances in Conventional Hearing Aids Have Reduced Feedback

Advanced digital signal processing in modern day CHAs has, on its own, reduced audible feedback, making the traditional techniques for reducing feedback not as

crucial for many patients. Modern CHAs have digital feedback suppression (DFS) that, when used appropriately by a clinician, effectively reduces, and often eliminates, acoustic feedback. The clinician often has control over the activation and/or strength of the DFS approach in the computer software.

In modern high-end CHAs, DFS allows an addition of 9 to 16 dB of gain around the feedback critical area of 2 to 4 kHz before feedback is audible, with the effectiveness varying among manufacturers.[16] In lower end products, feedback management capabilities may be less effective. The additional gain allowed by DFS before feedback is audible allows individuals with more significant hearing loss to be fit with smaller custom CHAs (ie, completely-in-the-canal CHA) or less occluding CHAs using an open-fit style or a larger vent.

Combining Digital Feedback Suppression with Traditional Approaches

Although DFS provides effective feedback reduction, the traditional approaches for decreasing feedback may still be required. Properly fitting CHA shells and ear molds and appropriate vent size will still be needed when DFS does not provide enough protection against feedback, which is most likely to be the case for patients with significant high-frequency hearing losses.[15] As noted elsewhere in this article, the tradeoff of providing a patient with closer fitting CHA shells or ear molds and smaller vents is the possibility of creating the occlusion effect or physical discomfort.

Feedback Persists with User Error

A persistent problem with CHAs in general is user error, which plagues feedback, particularly in those with severe hearing losses (for whom DFS has not eliminated the problem). With DFS, feedback can, in theory, be eliminated or reduced significantly in the clinic for even those patients with severe hearing losses by ensuring a tight fit of the CHA shell or ear mold and proper insertion into the ear. However, user error, in the form of improperly inserting the CHA, results in audible feedback. Despite the clinician counseling the user on proper insertion, many patients, especially those with dexterity and/or cognitive declines, may not achieve optimal CHA placement. Even patients with good dexterity may struggle with proper placement should they have especially narrow or curvy ear canals. Noncustom ear pieces (eg, domes that are commonly used today with RIC CHAs to maximize comfort) can work their way out of the ear throughout the day even with precise insertion.

OTHER COMMON CONVENTIONAL HEARING AID COMPLAINTS AND ISSUES THAT MAY BE SOLVED BY IMPLANTABLE DEVICES

Comfort and Retention

Ear mold or CHA shell fit and retention (ie, CHAs falling out of the ear) may be problematic for CHA users. A poor CHA fit may result in itchiness and irritation and, in turn, decreased CHA use. Retention, and the resulting frequent reinsertion, can similarly lead to itchiness, irritation, and decreased CHA use, including as a result of lost or damaged CHAs. Although many CHA users will adapt, and the bothersome sensation will pass, for others, it will persist. There are many techniques a clinician can use to alleviate the irritation. For open-fit style CHAs, the clinician can change the dome style and/or tip. The tube or wire may be too short or too long and require a clinician testing different sizes to find a depth that is comfortable for the patient. Changing manufacturers can also be beneficial, because the shape and size of the domes, receivers, wires, and/or tubes are physically different across manufacturers.

Poor-fitting molds are one of the most frequent causes of irritation in CHA users, necessitating that clinicians solve for CHA fit to improve patient comfort. Custom

molds with large vents may enhance comfort for open-fit style CHA users by providing a more stable fit in the ear canal. Custom molds can also be made for closed fitting CHAs. A clinician can often improve a poor-fitting mold by making modifications in the office (eg, buffing) or by taking a new ear mold impression using a different technique (eg, open jaw or closed jaw) or a different material (eg, acrylic) to be sent to the manufacturer. Even simply applying lubrication on the mold may improve the comfort of a custom or noncustom CHA.[17] With trial, error, and patience, most fit-related complaints can be ameliorated. However, for patients who remain dissatisfied and are unable to tolerate a CHA, an implantable device may become the appropriate choice.

Allergies

Allergic reactions to ear molds materials are uncommon, but possible. Switching the ear mold material from one type (eg, acrylic, vinyl) to silicone solves the problem for the majority of patients. However, silicone ear molds can also be problematic for some users by being difficult to insert, especially for those with very soft ears, or providing too tight a fit. Silicone molds typically provide a tight fit in the ear, which may pose a tolerance (ie, discomfort) problem for some patients.[18] Decreasing the size of the ear mold, a logical solution to a tight fit, can, in turn, lead to retention issues or make the CHA susceptible to feedback. Of course, some patients may also be allergic to silicone itself. For those patients who are also allergic to, or struggle using, silicone-based ear molds, an implantable device may be an appropriate solution to an acrylic or vinyl allergy.

Promoting Infections

Occluding the ear canal with an ear mold or CHA shell can induce or sustain external or middle ear infections by causing or exacerbating humidity in the ear canal. CHAs are simply not recommended for patients with chronic drainage. Venting the ear mold or CHA shell, or using an open-fit style CHA, can decrease or eliminate the moisture build up in the ear canal. Although venting will make the ear less prone to infection, allowing air into the ear canal can cause sound to leak out, making the CHA susceptible to acoustic feedback.

Infections, and the drainage caused by them, in addition to being uncomfortable for patients, may make the CHA prone to device failure for those patients with ITE and RIC CHAs, because the receiver and other electric components are in the ear and can malfunction when exposed to moisture. BTE CHAs may be appropriate for patients prone to infection, and the accompanying drainage, because all the components of the device are behind the ear and the ear mold can be cleaned and disinfected. For patients who prefer the RIC-style CHA for cosmetic reasons, modern BTE CHAs can use a thin tube for a more conspicuous appearance. A BTE CHA, coupled with a dome for an open fit, will minimize occlusion as well. Although no electronic components are in the ear canal in a BTE-style CHA, moisture can build up in the tube (even thin tubes) and cause damage to the CHA. Open-fit style CHAs, especially when used with a BTE, may lessen the threat of creating or exacerbating infections and device failure; however, they also may occlude the ear canal and, accordingly, not be appropriate for patients suffering from chronic infections. Chronic infection can often be managed by careful CHA selection, but severe cases may be a reason for a patient to switch to an implantable device.

Amplifying Conductive and Mixed Hearing Losses

Historically, studies showed that patients with 25 to 30 dB air–bone gaps performed better with an OI than a CHA, leading researchers to conclude that speech perception

was better with OIs than with CHAs. At the time the studies were performed, amplification of CHAs was reduced to avoid feedback, a problem that is less common in modern CHAs.[19,20] Wolf and colleagues[20] (2010) fit patients with mixed hearing losses with modern CHAs, including feedback suppression technology, that were able to provide adequate amplification with no audible feedback. The study by Wolf and colleagues determined that patients with mixed hearing losses and a severe air–bone gap (30–35 dB or greater) still do better with OIs compared with BTE-style CHAs, having better speech recognition and preferring the sound quality with acoustic feedback no longer explaining the preference for OIs. Based on these results, OIs should be considered for patients with a severe air–bone gap.[21]

For patients with a CHA with significant air–bone gaps, the prescribed gain and maximum output requirements of a CHA is different than for patients with a CHA with sensorineural hearing loss. Hearing losses with air–bone gaps typically require less compression than sensorineural hearing loss. A substantial hearing loss with a significant air–bone gap, requiring a considerable amount of gain, can make the CHA particularly susceptible to feedback and more so than a similar hearing loss in a patient, whose loss is sensorineural in nature. Accordingly, for those air–bone gap patients, an OI can be an appropriate solution to decrease audible feedback.

Substantial gain requirements for patients with an air–bone gap can also pose a CHA style issue. Smaller CHA styles, such as ITEs or RICs, may not provide enough power even at the maximum output to support a patient's needs, necessitating the use of power BTEs. However, the size and visibility of a power BTE-style CHA may not be desirable to some patients. Clinicians should be cautious not to placate a patient by choosing a CHA style that, although less visible, offers inadequate maximum pressure output capabilities for the patient's needs. Setting a CHA to its maximum capabilities can degrade the sound quality owing to the saturation of high input level of both speech and nonspeech inputs.[21] In such circumstances, where a patient needs, but wants to avoid, a power BTE-style CHA, an OI may be offered as a solution.

WHEN CONVENTIONAL HEARING AIDS CAN STILL BE EFFECTIVE AND WHEN CONVENTIONAL HEARING AIDS REACH THEIR LIMIT

The inverse relationship of troubleshooting occlusion effect and audible feedback has historically plagued the use of CHAs. To reduce the occlusion effect a clinician will often open the ear canal by venting or by using an open-fit style CHA. By opening the ear canal, the CHA user is then subject to audible feedback, because the open canal allows significant sound to leak out of the ear. To decrease feedback, a clinician can then reduce the vent size or create a tighter fit, but that results in possible occlusion effect. When ensuring a comfortable physical fit or venting the ear canal for medical reasons, the risk of occlusion or feedback may be exacerbated.

As seen with the data obtained from MarkeTrak 9, CHA satisfaction has increased dramatically in recent years. The advent of DFS, and its significant improvement in modern CHAs, has allowed for audible feedback reduction while allowing the ear canal to remain open (ie, not creating the occlusion effect). DFS has undoubtedly contributed to patient's high CHA satisfaction rate. Many patients with mild to moderate hearing loss, and sometimes even more severe hearing loss, are now able to be successfully fit with their preferred CHA style and a comfortably fitting device.

Even if modern CHAs are used properly, audible feedback may still plague those with more significant hearing losses. Those with near-normal low-frequency hearing loss and severe-to-profound high-frequency hearing loss may not be able to achieve a satisfactory reduction of the occlusion effect without adding audible feedback. To

eliminate the whistling, the clinician may have to make gain reductions to the high frequencies, compromising audibility. With increased satisfaction of CHAs, as seen in MarkeTrak 9, and evidence that implantable devices and optimally fitted CHAs have similar functional gain and speech recognition improvements,[15] the competitive advantage of MEI for many patients with moderate to severe sensorineural hearing losses may be reduced. For patients with significant hearing losses, however, it may not always be possible to (1) achieve an acceptable balance between occlusion effect and feedback, (2) ensure feedback does not occur without significantly reducing gain/audibility, and (3) guarantee a good comfortable physical fit. For these patients, MEIs and/or OIs may be an excellent alternative to CHAs.

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