Physical Options for Custom Hearing Aids

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ABSTRACT

Selecting appropriate custom in-the-ear amplification is a process of integrating shell and circuitry characteristics that satisfy what the patient wants and needs with what is physically and electroacoustically possible. Options are influenced by many factors, including ear anatomy, type and degree of hearing loss, medical conditions, lifestyle and an individual's capabilities and communication needs. This article provides a practical overview of criteria used in the selection of hearing aid type, shell construction, special features or accessories, and discusses the acoustic advantages of custom hearing aids.

KEYWORDS: Amplification, selection criteria, acoustic advantages of custom hearing aids, directional microphones

Learning Outcomes: As a result of this activity, the reader will (1) be able to list several advantages of custom hearing aids over behind-the-ear hearing aids and noncustom, instant-fit, hearing aids; and (2) give suggestions for troubleshooting feedback and occlusion.

The purpose of this article is to provide an overview of the options available to audiologists who select custom in-the-ear hearing aids for their patients. Fitting hearing aids is an inexact science requiring the incorporation of numerous direct and indirect factors in the selection and fitting process. Individual patient differences in ear anatomy, type and degree of hearing loss, combined with earmold acoustics and the electroacoustic characteristics of hearing aids influence fitting options. There are both electronic and acoustic solutions to universal problems such as feedback, occlusion, and optimizing intelligibility of speech in noise. In this discussion, custom hearing aids are distinguished by the following nomenclature: ITE refers to a full shell or low profile in-the-ear hearing aid; ITC refers to an in-the-canal hearing aid; and CIC refers to a completely-in-the-canal hearing aid.

CRITERIA FOR CHOOSING STYLE

Custom hearing aids account for ~80% of all hearing aids sold worldwide. In this millennium, transducer size is no longer an important issue in determining physical options in custom aids.

Ear Impression for the New Laser Shell Technology; Editor in Chief, Catherine V. Palmer, Ph.D.; Guest Editor, Chester Z. Pirzanski, B.Sc. *Seminars in Hearing*, volume 24, number 4, 2003. Address for correspondence and reprint requests: Gail I. Gudmundsen, Au.D., Etymotic Research, Inc., 61 Martin Lane, Elk Grove Village, IL 60007. E-mail: gudhear@aol.com. [1]Etymotic Research, Inc., Elk Grove Village, Illinois. 00734-0451,p;2003,24,04,313,322,ftx,en;sih00276x.

Directional microphones are now effective in canal aids, due to their reduced size, the appropriate selection of internal time delay, and the discovery that improved performance in noise is achieved by placing the directional microphone above the tragus in canal aids.[1] Even now the best BTE directional microphones provide 1–2 dB less directivity than ITEs[2] due to diffraction of sound around the pinna. Port spacing, once considered the critical issue in directional microphone applications, is no longer a limitation because of advances in directional microphone design. Circuits that feature feedback suppression, electronic damping, and reduction of the occlusion effect also lift many of the restrictions of a decade ago, but physical and acoustic factors continue to influence some style choices.

Many new hearing aid users come to their initial evaluation with an idea of the devices they want to wear. This may be based on what they have seen advertised, observed a friend or relative wear, or simply want "the ones that don't show." Many experienced hearing aid users express a preference for a certain style because they want to (1) replicate what they are already using, (2) change to something more cosmetically appealing, or (3) obtain features their current hearing aids do not provide. Patient motivation is critical to success with amplification. Experienced practitioners know that when patients' preferences and expectations are fulfilled, they will be more likely to work cooperatively during the trial period and beyond. Studies correlating personality traits with pre-fitting expectations indicate that extroverted patients report more benefit from their hearing aids. Persons who feel in control of their lives and those without a lot of anxiety also report greater benefit with amplification.[3]

DEGREE AND SLOPE OF HEARING LOSS

Degree of Hearing Loss

Degree of hearing loss will always be one of the determining factors in selection of hearing aid style, but there are many factors that need to be considered before a certain style is selected or ruled out. From the mildest hearing loss to a severe/profound hearing loss, an ITE aid or possibly an ITC or CIC may be appropriate. The combination of circuit options, venting, earmold material, hearing aid canal length, loudness tolerance, ear canal characteristics, and whether the hearing loss is asymmetrical are all part of the equation. Persons with conductive and mixed losses require greater gain and output sound pressure level for a 90dB input (OSPL90) than those with the same degree of sensorineural hearing loss. Patients will consequently have different requirements for shell size and circuit characteristics depending on the degree and type of hearing loss. Practitioner and patient expectations must be realistic, but clinical judgment is gained when borderline fittings are undertaken.

Slope

Amplification for precipitous high frequency hearing loss is a fitting dilemma. Some researchers advocate fitting the slope and abandoning unreachable regions based on the assumption that amplification in the mid frequencies may be sufficient to improve speech intelligibility by making the second formant (usually below 2 kHz) and transitions audible. Some patients with high frequency hearing loss describe a loss of tonality in the high frequencies in which sound is reportedly audible, but it is perceived as a hiss or buzz rather than a tone. The potential for feedback and patient discomfort from a large amount of high frequency gain may partially determine the limits for achieving audibility, particularly if it can be determined that additional gain will produce little or no improvement in word recognition. Studies indicate that providing additional high frequency amplification can sometimes be detrimental and lead to decreased word recognition scores.[4–8] This has implications for clinical practice. If there is any doubt whether to give up on the high frequencies or fight for them, it is useful to predict which patients will perform better with or without high frequency emphasis. The QuickSIN Test (Etymotic Research, Inc., Elk Grove Village, IL),[9] developed to assess word recognition performance in noise, contains tracks with sentences that have high frequency emphasis and tracks with sentences that are low-pass filtered. By comparing performance between these lists, it is possible to assess whether high frequency emphasis helps or degrades speech intelligibility in noise. Keep in mind, however, that some patients may receive benefit from high-frequency-emphasis over time, so it is important to consider acclimatization when making fitting decisions and fine tuning adjustments.

There is a growing interest in identifying dead regions of the cochlea (complete loss of inner hair cell function in a specific area). Dead regions, thought to be common in persons with moderate-to-severe sensorineural hearing loss, cannot be reliably determined from the audiogram, although certain patterns are beginning to emerge. Determining psychophysical tuning curves[10] is too time consuming for clinical practice, but the measurement of detection thresholds for pure tones in threshold equalizing noise (TEN) may prove to be clinically useful.[11] The future clinical utility of this information may assist practitioners in selecting, fitting and adjusting amplification and could influence style choice and circuitry options.

SIZE AND SHAPE OF THE EXTERNAL EAR AND EAR CANAL

Manufacturers' suggested fitting ranges are used as guidelines, but there are many situations in which the style of instrument will be determined by factors other than degree and slope of hearing loss. If a particular shell option appears to be on the borderline of a recommended fitting range, the dimensions of the ear canal, the intended placement of the microphone and ear tip, and the impedance of the middle ear can help predict if it is realistic to try that style. Adults and children with the same hearing loss will have different gain and output requirements because of the differences in ear canal volume. Ear canal volume is smaller in children than adults, resulting in higher ear canal SPL. This has a significant influence on the interpretation of diagnostic tests, real ear measurements, and the response characteristics of the hearing aids. With deep canal fittings (regardless of shell style) there is an increase in gain, output, and high frequency emphasis with deep placement of the ear tip.

Except for obvious physical conditions such as atresia, a malformed pinna or concha, or a surgically modified outer ear or ear canal, it is often difficult to predict that a patient will have good results from a particular type of shell on the basis of physical and otoscopic inspection of the ear. Depending on the shape of the concha, there are some cases when retention is actually improved with a CIC, ITC, or half-shell aid over a full-concha style. If the hearing loss is well within a fitting range, CICs or ITCs may be the best choice for some patients. It should not be assumed on the basis of visual inspection that an ear is too small for a particular style. Components can be placed in various arrays depending on the space available. The audiologist should choose the venting and circuitry, but the laboratory can determine how the bores, vents and components will fit. The audiologist can then verify the physical and electroacoustic appropriateness of the devices.

In a surgically modified ear canal with a large volume of 5 to 10 cc, the output speech production level can decrease by 10–20 dB SPL.[12] Conversely, a stiff middle ear system secondary to ossicular fixation, tympanosclerosis, or other condition, can increase eardrum SPL (gain and output) by 10–20 dB.[12] Surgical alteration of an ear canal also will affect real ear measurements. In these cases, real ear aided gain targets, rather than insertion gain targets, will be more useful in hearing aid fitting. It is necessary to add real ear unaided gain (REUG) to the insertion gain target to convert it to a real ear aided gain (REAG) target. At the present time only Desired Sensation Level (DSL) and NAL-NL1 (National Acoustics Laboratory [nonlinear fitting formula]) prescriptive methods do this automatically.[13]

MEDICAL CONDITIONS

The etiology of the patient's hearing loss and medications may influence style options. The choice could depend on whether the hearing loss is stable, fluctuates or is progressive. Ongoing medical management also must be considered. Is there chronic or recurrent middle ear pathology? If there is drainage, a shell with a very large vent is preferable to a more occluding shell, but with most circuitry there is a risk of feedback at higher gain settings. For some patients, BTEs may offer better flexibility. Individuals with chronic otologic conditions may have to alternate ears or decrease the use of a hearing aid in one ear during periods of fluctuation, infection or drainage. When an ear cannot be occluded and a large amount of gain is required, a CROS (contralateral routing of signal) instrument may be an option. In this configuration, a non-occluding earmold can be used in the ear with the pathology. Feedback is unlikely because the head shadow provides an additional 10 to 20 dB of isolation. CICs may be contraindicated for patients taking medication such as aspirin or anticoagulants, or for persons with temporal mandibular disorder (TMD), exostosis, or diabetes. Patients taking aspirin or other anticoagulants, or persons who have decreased rates of healing (such as diabetics) are at risk of bleeding and lesions that may occur as a result of abrasion from the insertion/removal of a deep CIC. Depending on the orientation of the CIC in the ear canal as it relates to the articulation of the temporal mandibular joint, a comfortable fit may not be achievable in persons with TMD. Completely soft CIC shells[14] could eliminate discomfort in some cases. Exostosis is a benign condition in which bony growths are present in the external ear canal; CICs are not always the best shell choice for these patients.

DEXTERITY

Changing batteries, adjusting rotary controls, switches, or push buttons for volume control, T-coil, direct audio input or directional microphones can be problematic for persons with limited dexterity. Small hearing aids are not the aids of choice if a person's manual dexterity precludes easy insertion and removal of custom shells, particularly CICs. Ease of management may be improved with the addition of screw-set volume controls, removal strings, removal notches, built-up controls, batteries with long pull tabs or packaging that facilitates easy insertion, modified battery doors (to accept a battery either way), automatic T-coil activation, magnets to extract and replace batteries, cerumen guards, wind screens, helix locks, and canal locks.

It is difficult to predict who will need or want manual controls. Some patients prefer no adjustments, but there are patients with "automatic" hearing aids who still prefer some degree of manual control. Push button switches are available for functions such as T-coil, volume control, or multiple memories. Remote controls make certain styles possible and sometimes preferable. If a practitioner thinks a particular style of hearing aid compromises ease of management, it will save time and disappointment if the patient is asked to perform potentially difficult tasks before final decisions are made regarding style and features. Users will usually acknowledge their limitations and opt for the style best suited to their abilities.

OCCUPATION AND LIFESTYLE

A patient's occupation may require the use of hearing aids with telecommunications equipment, stethoscopes, headsets, broadcasting equipment, or other assistive devices. Seamless integration of hearing aid use into a patient's normal routine is the goal.

For example, many medical practitioners use stethoscopes. Some earmold laboratories offer couplers or adapters for stethoscope eartips, which eliminates the need to remove hearing aids prior to use. Stethoscopes can occasionally be used with CICs (with deeply recessed faceplates) that require little or no stethoscope modification. BTE earmold modifications also are possible, but the effectiveness of using the patient's own hearing aids with modified earmolds will depend on the earmold characteristics required for use with the BTE. Amplified stethoscopes are an option, but removal of hearing aids is usually necessary.

There are many creative ways to connect hearing aids to electronic equipment in the workplace. Connectors, jacks and adapters are available to make headsets compatible with telephones and office equipment. Earphones can be worn over most custom hearing aids without feedback or discomfort. In special cases, hearing aid manufacturers may modify the faceplate of a custom shell to accommodate a direct connection to various types of broadcast, recording and monitoring equipment. Wireless technology will soon make it easy for hearing aid wearers to switch back and forth among various types of audio sources without changing earmolds or hearing aid settings.

For strenuous physical activities or sports, a style of hearing aid should be chosen that is compatible with the level of activity. Wind noise, perspiration and security of fit also should be considered when making decisions about style. Listening conditions vary, especially for more active persons, and activities such as attending lectures, theater, meetings and social gatherings place higher communication demands on the hearing aid user. It is useful to assess the activities in which the patient participates daily, weekly or only occasionally before presenting hearing aid options.

AGE AND PREVIOUS HEARING AID EXPERIENCE

With the exception of infants and young children whose ear canals are changing quickly, there is no compelling evidence to consider age or previous hearing aid experience in choosing hearing aid style or circuitry. The shell style that is most appropriate for the acoustic needs of the patient and for the ease of management for the patient, parent, or caregiver is the style that should be chosen. The choice of circuitry options and special features depends to a large extent on the practitioner's understanding of the rationale and intended application of various prescriptive formulae. Different procedures produce different prescriptions. Some of these formulae are based on age and individual audiometric data, others on average data. Multi-memory hearing aids may require a different prescription for each program, depending on individual patient needs and capabilities.

COST

The decision to purchase hearing aids may be influenced by financial considerations. Cost is one of the top five reasons for nonpurchase of hearing aids.[15] With some exceptions, the smaller the custom hearing aid (CIC versus ITE), the higher the cost. Hearing aids with digital signal processing and special features such as directional microphones, multiple memories, and remote controls cost more than conventional, single memory hearing aids with analog circuitry. Third-party payers may provide a fixed benefit and patients may not be willing or able to upgrade to the style and circuitry they prefer. Alternative funding sources such as supplemental health care and ancillary insurance benefits, or discount plans can be explored. Low-cost options are available, but price, quality, and effectiveness vary. Mail order, Internet sales of hearing aids, disposable hearing aids, and changing delivery models all affect the cost of hearing aids. Instant-fit hearing aids are sold in one size with a small selection of noncustom eartips to improve fit. Entry-level hearing aids are available in different styles, usually with basic circuitry. There may be some customization of shells within this group, but in general they have limited flexibility by design and are intended to introduce amplification to those patients who might not otherwise be inclined to purchase more expensive instruments.

SHELL DESIGN

Custom hearing aid shells are not simply housing for electronic components. Shell construction significantly influences the response of the hearing aid in an individual ear. The size of the bore, the diameter and length of receiver tubing, canal depth, and vent size and angle all are critical to the acoustics of the hearing aid response. Many of these factors also determine whether or not there is good seal integrity or occlusion effect. Some shell options are chosen purely for comfort or cosmetic reasons, but most styles can be built to achieve a specific acoustic benefit. It is important to understand the basic concepts of earmold acoustics and how the shell can be modified to give a better response when fitting problems arise. One of the most important factors to consider is where the eartip will seal in the ear canal. A deep canal fitting refers to the depth of the eartip in the ear canal, not how far the faceplate is recessed into the ear canal.[16] A shallow eartip and a deeply-sealed eartip produce entirely different acoustic responses, including different amounts of low-frequency attenuation or occlusion effect.

PHYSICAL FIT

The fundamental elements of a successful shell fit are comfort, retention and seal integrity. Performance can be verified with electroacoustic tests, real ear measurement, and other outcome measures. Various options are available when an earmold is too loose or moves excessively with jaw movement. Retention can be enhanced with a canal lock, helix lock, seal retention ring, a flex canal, or shell coating. If the seal is adequate, feedback may need to be managed electronically. Temporary solutions such as foam o-rings, adhesive strips or building up the shell will make troubleshooting easier if feedback can be reduced or eliminated. A shell that is either too tight or too loose can result in discomfort, occlusion or feedback, which can degrade performance. If the shell cannot be modified to improve fit and comfort or achieve the desired acoustic properties, a new shell (recase) is required. From time to time it is helpful to re-verify shell fit, seal, and hearing aid performance to confirm that the patient continues to receive maximum benefit.

There is no substitute for taking a good impression. *All* earmold impressions should extend past the second bend of the ear canal, regardless of the desired shell style or canal length. A good earmold impression will give the laboratory more information from which to make a properly fitting shell for all canal lengths. Guidelines for choosing impression materials and taking earmold impressions, including the benefits of open-jaw impressions are addressed elsewhere in this *Seminars* issue.

ACOUSTIC ADVANTAGES OF CUSTOM HEARING AIDS

The combination of shell acoustics, circuitry, and the physical properties of the ear determine hearing aid performance. A BTE may be the best choice when: (1) feedback cannot be controlled in a custom aid; (2) the user reports better performance and sound quality (e.g., reduced occlusion effect or more natural sound when coupled to a BTE earmold); (3) certain features are not available in a custom aid; or (4) management is easiest with a BTE hearing aid.

The major acoustic advantage of in-the-ear styles over BTEs is microphone location. ITCs and CICs (and ITEs to a lesser extent) better preserve the natural pinna and concha focusing effects and cues for sound localization than BTEs. ITEs have a 1–3 dB signal-to-noise advantage[17,18] over BTEs. CICs have better cosmetic appeal, security of fit, reduced wind noise,[19] and ease of use with the telephone, headsets, and stethoscopes. CICs generally seal more deeply in the ear canal than other custom hearing aids, which can reduce or eliminate the occlusion effect. The average decrease in occlusion effect in one study was 18 dB at 250 Hz with a deeply-sealed CIC compared with a medium-length ITE canal.[20] (This advantage is not restricted to CICs; a deeply sealed eartip on any hearing aid earmold or custom shell will reduce or eliminate the occlusion effect.) Modification of a CIC shell will affect its acoustic properties. Tapering the eartip may reduce the occlusion effect at 125–300 Hz but increase it by as much as 6 dB at 400 Hz. Tapering also could create venting that will change low-frequency gain.[21]

CICs have additional advantages over ITEs. Pinna and concha cues for localization are preserved in their entirety up to ~15 kHz with the microphone located inside the ear canal entrance.[22] A CIC with the same 2-cc coupler specifications as an ITE will have a progressively better high frequency response due to a deeper microphone location and a deeper eartip placement in the CIC. The smaller residual volume in front of the eartip of a typical CIC increases SPL at the eardrum by ~4 dB in the low frequencies and 8–10 dB at 4000 Hz.[23] Gain is increased even more. The deep microphone location adds additional high frequency boost. The total gain increase of a deeply-sealed CIC over an ITE is as much as 5 dB at low frequencies, and 13 dB at 4000 Hz.[23,24] These data, however, were obtained on early CICs. The current use of smaller components in CICs has reduced the size and canal depth of many CICs. The smaller, shorter CICs have reduced the magnitude of these gains in many cases. The equivalent volume of the ear behind a typical ITE is not 2cc, but closer to 0.7 cc. The eardrum adds 0.65 cc equivalent volume at low frequencies for a total effective volume of 1.35cc. In a deeply sealed CIC, the air volume is only ~0.25 cc giving—with the eardrum—a total effective volume of 0.9 cc. As a result of the reduced volume of air, the CIC aid will typically have ~4 dB greater undistorted output at low frequencies. At high frequencies, the increase is closer to 9 dB because the eardrum acts like a wall. The total of all effects gives the real-ear response of a CIC aid approximately a 14 dB high frequency boost relative to a full-shell ITE with the same 2cc coupler measurements (M. Killion, personal communication, 2002).

DIRECTIONAL MICROPHONE OPTIONS

The advantage of directional microphones is improved speech intelligibility in noise.[25] Directional microphones were first introduced in BTEs more than 30 years ago, but hearing aids at that time were either omni-directional or directional, not both; with the exception of only one or two BTEs, users could not switch in and out of the directional mode.

Switchable directional microphones are now available in custom hearing aids. Directional microphones in custom hearing aids can be selected manually or programmed into multimemory aids that are accessed by push button switch or remote control. Some directional microphone designs are adaptive (i.e., the hearing aid automatically switches to directional mode when background noise conditions are unfavorable). Early directional microphone designs for in-the-ear hearing aids depended on a critical separation between microphones to achieve adequate signal-to-noise ratio improvement. Fortunately, microphone spacing is no longer an issue due to advances in directional microphone design; excellent directivity of 5.8 dB is now possible in an ITC.[1] When ordering directional microphones in custom hearing aids, it is helpful to mark the horizontal plane on the earmold impression to provide the manufacturer with a guide for proper alignment of the microphones.

A patient's ability to understand speech in noise cannot be predicted from an audiogram.[26] There are speech-in-noise tests, (e.g., HINT[27] and QuickSIN[9]) that quantitatively assess a patient's signal-to-noise ratio (SNR) loss. Results of these measures help determine the need for a directional microphone (3–5 dB noise reduction), an array microphone (7–10 dB improvement in SNR)[28,29] or an FM system (15–20 dB SNR improvement). These tests are invaluable tools for counseling patients and families.

FACTORS THAT AFFECT DIRECTIVITY

Venting of the earmold or shell and preset frequency response of directional microphones affect directivity. As vent size increases, effective directivity decreases.[30,31] Vents can add unwanted noise coming in through the vent, as well as reduce low-frequency gain for sounds in front of the patient. Despite reduced directivity, a 3-mm vent can still provide an improvement of almost 2 dB over an omnidirectional microphone in an ITE.[30] Many manufacturers use a low-frequency cut in directional mode, which will affect directivity. Patients with hearing loss in the low frequencies often report little or no benefit in directional mode when there is so much low cut that low-frequency speech cues are not audible. These patients hear better in noise when the frequency response of the directional microphone closely matches their hearing aid's frequency response. When ordering directional microphones for patients with flat or reverse-slope losses, or when thresholds at 250 and 500 Hz are 40 dB or greater, low frequency equalized directional microphones should be considered.

CONCLUSION

Selecting appropriate amplification is a process of choosing the combination of options that satisfies what patients want and need and what is physically and electroacoustically possible. Post-fitting troubleshooting, fine-tuning, and problem solving involve more than making changes to hearing aid settings. The process includes correctly identifying the problem and determining whether to adjust the hearing aids, make shell modifications or both. Experience is defined as knowing when to make adjustments and when not to make changes, but instead counsel patients about acclimatization. From the initial earmold impression to the selection of a remote control operated by hand or worn as a wristwatch, practitioners have an abundance of options from which to choose. The challenge is making the correct selections.

ABBREVIATIONS

BTE	behind-the-ear
CIC	completely-in-the-canal
CROS	contralateral routing of signal
DSL	Desired Sensation Level
FM	frequency modulated
ITC	in-the-canal
ITE	in-the-ear
NAL-NL1	National Acoustics Laboratory (non-linear fitting formula)
REAG	real ear aided gain
REUG	real ear unaided gain
SNR	signal-to-noise ratio
SPL	sound pressure level
TEN	threshold equalizing noise
TMD	temporal mandibular disease

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