Chapter 179: Amplification Devices for the Hearing-Impaired Individual

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Hearing impairment affects persons of all ages. Presently, 21.9 million Americans, or 9.1% of the population, suffer some degree of hearing loss. Some hearing loss may be nonreversible and can be helped only with the use of amplification. The otolaryngologist must be familiar with the nature of hearing loss and the ways in which available technology can change the quality of life of hearing-impaired individuals.

Nature of Hearing Loss

Hearing impairment is the inability to perceive and understand acoustic stimuli. It results from physiologic changes within the individual's auditory system. The consequence of such changes can be modeled as a diminishment in the sensitivity to auditory stimuli *(attenuation factor)* and an alteration in the characteristics of the auditory stimuli being perceived *(distortion factor). Conductive* hearing loss results mainly in attenuation of the acoustic signals. *Sensorineural* hearing loss, however, results in a combination of attenuation and distortion factors. These factors contribute variously to the hearing-impaired individual's communication difficulty. The use of properly fitted amplification devices can alleviate problems caused by attenuation; communication difficulties that result from purely distortion factor are more difficult to correct. It is encouraging to note, however, that present-day hearing aids do offer some benefits to a majority of hearing-impaired patients. Indeed, over 90% of today's hearing aids are worn by individuals with primarily sensorineural hearing loss. Assistive listening devices (ALDs) are also used to help these individuals.

Hearing Aids

A hearing aid amplifies sounds in specific frequency regions. Ideally, and in a simplistic sense, the region of amplification should correspond to the region of the hearing loss. The rationale is to overcome the attenuation that results from the hearing loss. Hearing aids can be broadly classified into acoustic and electronic devices.

Acoustic devices

Acoustic devices are based on the principle of acoustic resonance. Any cavity has a frequency region at which the mangitude of an incoming acoustic signal is amplified, that is, *resonance* frequency. The exact frequency region where resonance occurs depends on the dimensions of the cavity. Examples of acoustic devices are acoustic horns and trumpets, Goode's Innovaid ear bubble, and hand-cupping behind ears. These devices can provide up to 15 dB of amplification in the 500 to 1500 Hz frequency region. For this reason, these devices may be appropriate for persons with a mild hearing loss in the midfrequency range. Fig. 179-1 shows a modern acoustic device, the Innovaid acoustic bubble.

Electronic devices

Electronic devices include hearing aids and ALDs. Electronic devices are commonly used by hearing-impaired individuals.

Electronic devices have undergone dramatic evolutionary changes. Beginning with the use of carbon hearing aids in the 1930s, hearing aids used vacuum tubes and transistors for the amplifier circuit. These early devices had restrictive frequency responses, poor reliability, and high current drain. Some were bulky and cosmetically non-appealing. The advent of very large scale integration (VLSI) technology has reduced substantially the size of today's hearing aid amplifier circuits. The microphones, receivers, and batteries have become miniaturized also.

Along with technologic advancement, our knowledge about hearing loss and the way in which acoustic factors could affect hearing aid performance have increased also. As a result, present-day hearing aids are worn more satisfactorily than those in the past.

Hearing aid components

The principal components of a hearing aid are depicted in Fig. 179-2.

Microphone. Microphones transduce an acoustic signal into its electrical analog. Present-day microphones are mostly electrets and have broad-frequency response.

Microphones can be classified by their sensitivity to sounds from different directions, that is, *directionality. Omnidirectional* microphones have equal sensitivity to sounds from all directions, whereas *directional* (or *unidirectional*) microphones are most sensitive to specific directions only. Consequenly, directional microphones can exclude sounds that originate from specific directions. This characteristic can be useful in a speech-in-noise situation where the sources of speech and noise are physically separated. In these circumstances, the directional microphone is worn so that it is most sensitive to speech and least sensitive to noise.

The position of the microphone (on a hearing aid) affects its directionality and ultimately its performance. Ideally, the microphone should be placed at the entrance of the ear canal to mimic the behavior of the real ear. In reality, however, most hearing aids are not worn this way. Most microphones for behind-the-ear hearing aids are located near the top of the hearing aid. The microphones in some older models are located at the bottom of the hearing aid. Microphones on eye-glass-style hearing aids are either front-facing or on the underarm of the eye-glass frame. Microphone positions on inside-the-ear hearing aids vary from near the top of the concha region to the bottom of the concha region. Microphones for in-the-canal hearing aids are typically located near the entrance of the ear canal.

The performance of a microphone can be easily affected by moisture accumulation on its vibrating diaphragm. The output signal (from the hearing aid) will sound distorted, and the hearing aid may drain more current from the battery than usual. Some hearing aids may appear "dead" due to water damage.

Amplifier and associated filters. An *amplifier* increases the amplitude (that is, amplifies) of incoming signal, whereas a *filter* removes some frequency components of the signal. Amplifier and filter are usually encased within the body of the hearing aid. Amplifiers and filters typically occupied most of the space in older-generation hearing aids. Miniaturization has reduced the size of present-day hearing aid amplifiers to less than 0.1 inch.

Present-day hearing aids use either a linear or compression amplifier. Linear amplifiers provide constant amplification regardless of the level of the input signal. Compression amplifiers provide constant amplification up to a point (knee or threshold) and thereafter provide less amplification as the input level is increased.

One reason for compression hearing aids is the presence of recrutiment in most hearing-impaired individuals with sensorineural hearing loss. These individuals have reduced *auditory dynamic range* (defined as the range in decibels between threshold and the uncomfortable listening level). A compression hearing aid provides more amplification for the softer speech sounds so that they can be heard, but provides less amplification for the louder speech sounds so that they will not be too loud. Thus the amplified speech is within the individual's dynamic range, resulting in maximum speech intelligibility and listening comfort. Unfortunately, research and clinical studies on single-channel compression hearing aids have failed to demonstrate the superiority of compression circuits over linear circuits. The introduction of multichannel compression hearing aids and the use of more sensitive research protocols may reveal the benefits of compression hearing aids.

Recently, hearing-aid manufacturers introduced the so-called *noise-reduction* hearing aids. Such hearing aids amplify a relatively broad range of sounds when the input signal is soft, for example, in a quiet environment, but automatically reduce its range of amplification when the input signal is increased (as in a noisy environment). Although different manufacturers have different implementation of the noise-reduction circuit, most reduction occurs in the low-frequency region below 1000 Hz because most background noise is assumed to be low-frequency.

The efficacy of noise-reduction hearing aids is still under investigation. In general, noise-reduction hearing aids provide limited enhancement of speech understanding in noise. However, some wearers report that the listening environment is "less noisy" when a noise-reduction hearing aid is used. Other subjective benefits of noise-reduction hearing aids include more "comfortable listening" and improved self-perceived voice quality during vocalization (that is, less "talking through a tunnel" perception).

Receivers. The *receiver* (or loudspeaker) of a hearing aid transduces the amplified electrical signal into acoustic form. For a bone-conducting hearing aid, the receiver (vibrator) transduces the electrical voltage into mechanical vibration. For both air- and bone-conduction hearing aids, receivers had limited frequency response and could not be used successfully for individuals with high-frequency hearing loss. Present-day hearing-aid receivers have extended high-frequency range and can be fitted to those individuals more successfully.

Like microphones, receivers can be damaged easily by moisture. In addition, receivers in an in-the-ear hearing aid can be affected by cerumen accumulation. The hearing aid appears weak or dead. Cerumen is the major cause for in-the-ear hearing aid failure.

Volume control. The *volume control* is a potentiometer that the hearing aid wearer uses to regulate the amount of amplification. The volume control in most analog hearing aids is a numbered wheel/knob that increases the amplification when turned upward or forward and decreases the amplification when turned downward or backward. It must be emphasized that traditional volume control wheels are not linear. One may not receive twice as much amplification at a volume of "6" versus a volume of "3". Dust particles trapped between the volume control may result in "dead spots" from the hearing aid as the volume is turned.

Power supply. Hearing aids require power to operate. Power was supplied externally in older-generation hearing aids. Present-day hearing aids have an internal power supply by the use of button-type cells. Typical hearing aid batteries come in four sizes (675, 13, 312, and 10, in decreasing physical size, and power MAh, a unit for energy content) (Fig. 179-3). The most common type of hearing aid battery is made of zinc oxide (or the Zinc-Air battery) and has a voltage of 1.4 V. For most hearing aids, each zinc-air battery (regardless of size) typically lasts about 2 weeks with regular use. A hearing-aid battery is nonfunctional when its voltage falls below 1.2 V. Batteries should be handled with care.

Telecoil. Some hearing aids have a telecoil or T-switch. Telecoil transduces electromagnetic signals to electrical form. Electromagentic waves are inaudible to the ear and they radiate out of telephone receivers along with the acoustic waves. The use of a T-switch allows one to receive these electromagnetic waves. Because the microphone switch is typically deactivated when using the T-switch, acoustic feedback, which typically occurs as the telephone is placed near the hearing aid microphone, is avoided. In addition to the use on the telephone, the T-switch is necessary for use with some ALDs.

Styles of hearing aids

Present-day hearing aids are broadly divided into five styles. The emergence of a specific style is a result of technologic changes. However, each style has its advantages and disadvantages (Fig. 179-4).

Body aid. A body hearing aid is the oldest style of electronic hearing aid. The body hearing aid is typically worn around the waist or in the front of the chest. The output of the hearing aid is transmitted by a cord to the wearer's ear through the use of a regular earmold. Because the earmold (and receiver) is separated from the microphone, the chance of acoustic feedback is reduced. Body-style hearing aids are used primarily for individuals with severe-to-profound hearing loss.

Eyeglass aid. This style of hearing aid was popular in the 1960s. The electronic components of the hearing aid are housed within the frames of the eyeglass. A plastic tube leads from an outlet on the frame (receiver outlet) to an earmold. This style of hearing aid could be useful for any degree of hearing loss, but is not used as frequently now because of its physical ties to the eyeglass, which could be inconvenient for some patients. Furthermore, the frames of the eyeglass are typically thick and may not be cosmetically appealing.

Some manufacturers provide adapters to connect their behind-the-ear hearing aids to the patient's personal eye-wear. This eliminates the problems of unacceptable cosmetic appearance and poor microphone directionality. However, the hearing aid is still tied to the eyeglass.

Behind-the-ear (BTE) aid. This style of hearing aid was very popular in the 1970s and early 1980s. The hearing aid is worn over the ear, and is coupled to an earmold, which is inserted into the ear canal. This style of hearing aid can fit individuals with varying degrees of hearing loss, from mild to profound. Furthermore, these hearing aids have space to accommodate, sophisticated circuitry. Because BTE hearing aids are not custom-made, different BTE hearing aids can be tried before a particular BTE hearing aid is recommended.

Less than 20% of hearing aids dispensed in the United States in 1990 were behind-the-ear models. The major reason is that most of the newer generation in-the-ear hearing aids are just as efficient as BTE hearing aids in helping hearing-impaired individuals. The cosmetic appearance of the hearing aid also may be partly responsible for its declining popularity.

BTE hearing aids are clearly indicated over in-the-ear hearing aids for some patients. Patients with a mild-to-moderate degree of hearing loss and a history of chronic ear drainage may use a BTE hearing aid coupled with an open mold for ventilation. Furthermore, unlike an in-the-ear hearing aid, the earmold can be easily cleaned and sterilized. Behind-the-ear aids also may be more suitable for children. Because children's ear size changes with age, an in-the-ear style hearing aid may have to be recased, whereas one may only need to replace the earmold (that is coupled to the BTE hearing aid) at a substantially lower cost.

In-the-ear aid. This type of hearing aid is the most popular today. Over 80% of hearing aids sold in the USA in 1990 were in-the-ear (and canal) hearing aids. The hearing aids fits in the concha region of the ear. The popularity of this style of hearing aid is due to its cosmetic appearance and its comparable performance to BTE hearing aids. Furthermore, these hearing aids have better directional properties, are easier to handle, and can fit individuals with mild to severe degrees of hearing loss. The major disadvantages are the ease with which the hearing aids trap cerumen and the smaller battery, which may be more difficult for some elderly patients to handle.

In-the-canal aid. This style of hearing aid is increasing in popularity. The hearing aid fits iside the wearer's ear canal and is suitable for individuals with a mild-to-moderate degree of hearing loss. Some individuals with a moderate-to-severe degree of hearing loss also have reported benefits from the in-the-canal aid.

The in-the-canal hearing aid offers an acoustic advantage not seen in the other styles of hearing aids. The microphone of the hearing aid is located at the entrance of the ear canal, and the concha region of the pinna is unoccluded by the hearing aid. Consequently, the concha is left for natural resonance in the upper frequency regions (around 4000 to 6000 Hz). The major problem with this style of hearing aid is its tendency to trap cerumen. In addition, the wearer must have a large enough ear canal to allow enough space for the circuitry and for proper venting.

Hearing aid specifications

All hearing aid manufacturers provide electroacoustic specifications for their hearing aids. Furthermore, audiologists also routinely measure the performance of hearing aids. Such measurements are necessary to compare different hearing aids and to compare the same hearing aid over time. The availability of such specifications allows the audiologist to preselect hearing aids that could be beneficial for a particular hearing-impaired patient. A discussion of the major electroacoustic characteristics follows.

Maximum power output (MPO) or saturated sound pressure level at 90 dB input (SSPL90). The *MPO* or *SSPL90* of a hearing aid limits the maximum sound pressure level (in dB SPL) produced by the hearing aid, in much the same way as the ceiling in a house. Determining the most appropriate SSPL90 setting on a hearing aid is important in hearing aid selection. Hearing aids with a lower-than-optimal SSPL90 setting increase the likelihood of distortion from the hearing aids. The wearers will likely report poor sound quality from the hearing aid with comments like "muffled", or "blurry". On the other hand, if the SSPL90 is set too high, one may increase the risk of overamplification and result in additional hearing loss. Patients in this category complain that their hearing aids are "too loud". They also may set their hearing aids at a very low volume control setting. The optimal SSPL90 setting on a hearing aid is based on considerations of the patients' hearing loss, their tolerance for sound, and the environment in which they typically function.

Gain. The *gain* of a hearing aid refers to the amount of amplification (expressed in decibels) that the hearing aid delivers to the wearer. It is the difference between the output level from the hearing aid and the input level to the hearing aid. The amount of gain available when the volume control on the hearing aid is turned all the way up is called *full-on gain.* The amount of gain available when the volume control is set at the wearer's comfortable listening level is called the *user gain.* The full-on gain is determined by the hearing aid manufacturer. The user gain is set by the wearer. Ideally, the user gain should be about 10 to 15 dB below the full-on gain. Deviation from this range may suggest that the hearing aid is being used inappropriately.

The power of a hearing aid is determined by its full-on gain. Typically, a mild-gain instrument has a full-on gain between 20 and 30 dB, a moderate-gain instrument has a full-on gain between 35 dB and 50 dB, and a power instrument has a gain greater than 60 dB. In-the-ear or BTE hearing aids can yield as much as 65 to 75 dB gain. Body-style hearing aids can have as much as 80 dB full-on gain.

The choice of instruments with appropriate gain is important. Instruments with insufficient power will not yield the potential benefits of amplification. Instruments with too much power result in tolerance problems and additional hearing loss.

Frequency response. The *frequency response* of a hearing aid is the range of frequencies that the hearing aid amplifies. The *frequency response curve* of a hearing aid is a display of the gain of the hearing aid at different test frequencies.

A hearing aid with optimal frequency response enhances speech understanding and increases subjective listening comfort. Inappropriate frequency response may deter speech intelligibility and speech quality. The appropriateness of a hearing aid for a particular patient depends on the match between the frequency response of the hearing aid and the patient's hearing loss configuration, personal preference, and the listening environments. If all other variables are equal, a patient with equal hearing loss at all test frequencies may benefit from a hearing aid with a broad-frequency response, whereas a patient with hearing loss at restricted frequencies (for example, high-frequency loss) may prefer a hearing aid with a narrow frequency response.

Electroacoustic characteristics are determined in standardized measuring devices called *couplers.* A coupler is simply a cavity that simulates the average-sized ear canal volume. It is used for ease of comparison among hearng aids. The measured characteristics with a coupler are termed *coupler characteristics;* that is, coupler SSPL90, coupler gain, etc. When a hearing aid is worn, the difference in impedance and volume between the coupler and the patient's ear canal, and the loss of ear canal resonance due to the insertion of the earmold or ITE hearing aid, mean that the actual gain in hearing sensitivity may be different from coupler specifications. When the gain is measured in a sound field, the difference in thresholds between the conditions of not wearing a hearing aid (unaided) and wearing a hearing aid (aided) is termed *functional gain.* When the gain is measured with a probe microphone device, the difference in sound pressure level in the ear canal between the aided and unaided conditions is termed *insertion gain.* Although the measurement methods are different, the average functional gain and the average insertion gain agree fairly well.

Earmolds

Earmolds are ear inserts used with eyeglass, body, and BTE hearing aids. Although the primary purposes of earmolds are to help secure the hearing aid and to direct sound from the hearing aid receiver to the individual's ear, they also modify the frequency response of the acoustic output from the hearing aid. Properly fitted earmolds (that is, physical fit, style, materials, vents, and tubings) are just as important as properly selected electroacoustic characteristics. Indeed, earmolds can often affect the success of a hearing-aid fitting. Although the majority of hearing aids dispensed today are in-the-ear style hearing aids, some of the information presented here (especially venting) for BTE hearing aids is also applicable for in-the-ear hearing aids.

Earmolds can be made of different materials. The choice for a particular material is important for comfort and for obtaining a good seal. In general, softer materials (for example, silicon, vinyl) are more comfortable and pliable and can seal better than harder materials (for example, lucite, acrylic). Softer materials are recommended for individuals with severe-to-profound hearing loss.

Earmolds are available in different styles (Fig. 179-5). The three most common styles are the regular, skeleton, and open or nonoccluding earmolds. The regular earmold has the most bulk. It fills the ear canal and the whole concha region. The open earmold has the least bulk, typically consisting of a tube extending into the ear canal, and a rim around the concha region for retention. Skeleton earmolds are between these two styles in bulkiness.

In general, persons with more hearing loss require earmolds with more bulk for better seal. For the same hearing aid, a nonoccluding earmold will produce feedback first, and the regular earmold will produce feedback last.

The tubing used with the earmold can affect its performance. In general, tubings with wider inner diameter will accentuate the high-frequency sounds. Specialized tubing, such as the Libby horn, is shaped to increase the flow of energy above 3000 Hz by as much as 10 dB.

Regular and skeleton earmolds can be ordered with an air duct or a vent. A nonoccluding mold can be considered as having a large vent. The purpose of a vent is to equalize pressure and improve ventilation within the ear canal. Furthermore, vents attenuate low-frequency energy within the ear canal. Hearing aids coupled to earmolds with a vent are judged subjectively to have better sound quality than unvented earmolds. In addition, vented earmolds are associated with less perception of hollowness in one's own vice than with earmolds without a vent. Whenever possible, vents should be included in an earmold or in-the-hearing aid. It must be cautioned, however, that the presence of vents increases the likelihood of acoustic feedback and limits the amount of usable gain.

Assistive Listening Devices

As their name implies, ALDs are used to assist a hearing-impaired person's hearing. These devices can be used in place of, or augment the use of, hearing aids. Assistive listening devices can be categorized into four groups.

Enhancement of signal-to-noise ratio

Signal-to-noise ration (S/N) is a measure of the relative intensity of a signal to that of a signal to that of the background noise. It is usually expressed as a positive or negative number. Positive S/N ratio suggests that the signal (speech) is louder than the noise, and a negative S/N ratio suggests the opposite. A quiet listening condition can be expressed as a large positive S/N ratio, whereas a noisy condition can be expressed as a large negative S/N ratio. In general, speech intelligibility is decreased as the S/N ratio is decreased.

Several factors can affect the S/N ratio. Sound waves that are generated within a room bounce off from the walls as reflected signals. The reflected waves are heard as "echoes". In general, a room with more hard surfaces is more reverberant (echoic) than a room with soft surfaces. Reverberation increases the level of the noise and thus decreases the S/N ratio. As reverberation increases, speech intelligibility decreases. This phenomenon is demonstrated in the spectral display of the phrase "the beet again" recorded in a nonreverberant room (T = 0s) and a moderately reverberant room (T = 0.4s) (Fig. 179-6). Reverberation results in a smearing of the spectrum to result in poorer intelligibility.

The farther away a listener is from the speaker, the less intense the speaker's voice is to the listener. Assuming that the noise is constant, increasing the distance between a speaker and a listener will decrease the S/N ratio. Fig. 179-7 shows the relative decrease in sound pressure level as a function of the separation between speaker and listener. Line *a* represents the theoretical decrease in sound pressure level as a function of distance. Note that for every doubling of distance there is a 6-dB decrease in the level of the sound source. Line *b* is the level of the reflected sound within the room. Note that the level is constant throughout the room. Line *c* is the combined effect of distance and reverberation within the room. Point *D* represents the critical distance - the point at which the direct and reflected sounds are equal. The critical distance varies according to the reverberation time of the room.

The problems of distance and reverberation cannot be resolved by today's personal hearing aids, which amplify both speech and noise. That is one reason why some hearing-impaired patients complain that they can hear but not understand even with the use of hearing aids.

Some solutions to the problems of distance and reverberation include instructing the speaker to speak at a louder volume (that is, increase signal) or to reduce noise or reverberation. Both of these approaches may not always be practical. Another alternative is to decrease the distance between the speaker and the listener. The last approach can be accomplished through the use of hard-wired, FM, infrared, and telecoil devices.

Hard-wired devices

A microphone is placed or held near the speaker's mouth and the output is amplified and conducted to the headset by wires. Thus the microphone and headset are physically apart but connected (Fig. 179-8).

The advantage of a hard-wired system is that it increases the S/N ratio at a low cost to the hearing-impaired individual. In addition, it is not affected by electromagnetic interference originating from other sources. It can be effective for individuals who have difficulties in only restricted listening environments and who do not wish to use hearing aids. The major disadvantage is that the hard-wired systems limit the mobility of the user to that dictated by the wire. In addition, the frequency response of the hard-wired system may not match the configuration of the individual's hearing loss.

Telecoil/Induction-loop

To eliminate the need for hard wiring, one needs to change the signal to a different form for transmission or reception. One approach is to change the acoustic signal to an electromagnetic form, transmit it "in the air", and then reconvert it back to the acoustic form.

In its implementation, a microphone is placed near the speaker or source. The transduced signal is amplified and led to a wire-loop, which is usually placed around the baseboard of any room. The loop emanates an electromagnetic wave, which can be picked up by any hearing-impaired individual inside the room whose hearing aid has a telecoil or T-switch.

The use of telecoil gives the user freedom to move within the room without loss of mobility. However, its use is restricted to individuals who have a T-switch on their hearing aids. Furthermore, it is susceptible to electromagnetic leakage from nearby rooms that also use induction loops. Transmission by induction loop is also susceptible to interference from audiofrequency electromagnetic waves; for example, power-line frequency at 60 Hz and its harmonics.

FM system

In FM system, a low-frequency signal (for example, speech) is used to modulate a high-frequency carrier (typically in MHz). Because the carrier signal is inaudible, FM signals are inaudible until they are demodulated.

In its implementation, a microphone is placed close to the speaker. The transduced signal (in electrical form) modulates a high-frequency signal. The modulated signal is then transmitted (or broadcast), received, and demodulated into its original form (that is, original speech signal) without any noise contamination.

The demodulated signal can be treated in several ways. First, it can be amplified and heard through the use of headphones. Second, it can be coupled directly to hearing aids that are adapted to accept direct audio input. The use of hearing aids with an FM system ensures that the acoustic signals are shaped by the hearing aid to fit the configuration of the individual's hearing loss. Finally, the signal can be converted to electromagnetic waves and output via an induction loop. Individuals who have a telecoil on their hearing aids can use it to receive the electromagnetic waves.

The advantage of FM system is that the microphone transmitter and the receiver are not physically tied together. This suggests that the users can move freely within a range covered by the FM system (up to 600 feet), both indoors and outdoors, day or night. In addition, they do not interfere with a cardiac pacemaker, nor are they interfered with by electromagnetic waves. FM systems are especially useful for individuals with a severe degree of hearing loss. These systems are useful for hearing-impaired children in schools.

The major disadvantage of the FM system is its cost. Personal FM systems range in price from $500 to $900.

Infrared system

The infra-red system is based on a principle similar to that of the FM system except that infrared light, an invisible light beam, is used as the carrier of the speech signal (Fig. 179-9). Input and output options of the infrared system are comparable to those of an FM system.

Infrared transmission is especially useful for indoor use. A small, personal unit can transmit up to a radius of 30 feet. Larger, commercial units can transmit up to 4500 square feet. The results obtained with infrared systems are comparable to those obtained with FM systems. Infrared systems are also less expensive than FM systems. The major disadvantage of an infrared system is its restriction to direct line transfer, as light cannot transmit through obstacles. Furthermore, it cannot be operated outdoors, as the infrared light in sunlight can affect the integrity of the transmission.

Telephone devices

Hearing-impaired individuals can carry on conversations on their telephones through activation of a T-switch on their hearing aids. In addition, different devices are available to hearing-impaired patients, according to their needs and degrees of hearing loss (Fig. 179-10).

Telephone amplifier handset

An amplifier may be wired in the handset of a telephone to provide up to 20 dB additional amplification for hearing-impaired individuals. These amplifiers can be purchased easily from telephone display centers and some electronics stores. They can be appropriate for individuals with even a moderate degree of hearing loss. The only disadvantage is that one is restricted to one particular handset and may not be able to carry it around conveniently.

Portable amplifier

These devices are small adapters that can be strapped easily onto telephone receivers to increase output. They can be especially useful for hearing-impaired individuals who cannot be restricted to the use of one telephone. Portable amplifiers can be used alone so that the individual does not need to use a hearing aid while talking on the telephone, or they can be used in conjunction with personal hearing aids.

Telephone couplers

Acoustic feedback is a common problem that occurs when the telephone receiver is held close to a hearing aid (without the T-switch). This disadvantage limits the use of hearing aids while talking on the telephone. To reduce feedback, one must increase the separation between the telephone receiver and the hearing aid. This separation is accomplished through the use of a portable coupler that is placed over the telephone receiver. The height of the coupler increases the distance between the telephone and the hearing aid, resulting in less likelihood of feedback. In addition, the coupler attenuates some background noise for quieter conversation over the telephone.

Telecommunication devices for the deaf (TDD)

Individuals with severe-to-profound hearing loss may not benefit from the use of any telephone devices because of insufficient amplification and severe distortion that accompanies the hearing loss. Communication over the telephone must be achieved in a written mode through the use of TTDs (Fig. 179-11).

Users of TDDs must have compatible TDDs, and both parties (caller and respondent) communicate by typing on a keyboard. The message is then displayed either on a screen or on paper. If either party does not have a TDFD (the cost of a TDD is between $200 and $500), service from a message relay center is necessary to complete the call. To initiate the service, one party calls the message relay center either by phone or by TDD. The operator responds in a similar mode (voice or TDD) to that of the calling party, but calls the responding party in the opposite mode (that is, TDD or voice) to convey the message. Simultaneous exchange of information is possible. With passage of the American Disability

Act (ADA), it is anticipated that all states will provide relay service by 1993.

Warning and alerting devices

Although ALDs improve the hearing-impaired individual's communication ability, some of these devices may also increase the individual's awareness of their environments via visual, vibratory, or auditory modes. For example, the sound of a doorbell can be amplified (auditory), or it may be changed into a sequence of light flashes (visual). Telephone rings can be coded into light flashes. Alarm clocks can be coupled to vibrators that set off vibrations as they are triggered. A complete description of all the different devices is beyond the scope of this chapter. Interested readers are referred to catalogs (published by HARC Mercantile Ltd) for a complete listing.

Television viewing

While most of the devices described in the previous sections can be used for TV viewing, some patients may still find it difficult to understand some programs. A solution is to change the dialogue from an oral form to a visual form so that the hearing-impaired individual can read from the screen while listening to the conversation.

Telecaption decoders are available for commercial purchase (Fig. 179-12). The decoder is physically connected to the TV set. When the decoder is off, no written display is seen. When the decoder is on, writtent display of the conversation appears on the screen along with the regular program. At this point, captioning is mostly available for network news and prime time programs. A caption decoder can be purchased for about $200.

Hearing and Selection Process

The goal of hearing-aid selection should not be limited to finding a hearing aid that maximizes speech understanding. Rather, the goal should for an improvement of the individual's communication ability and quality of life. Hearing-aid selection must include an assessment of communicatin needs (or educational needs), motivation for the hearing aid, history of hearing-aid use, medical history, and hearing loss configuration.

Audiologists and otolaryngologists work together in the hearing-aid selection process for best patient care. The role of the otolaryngologist is to ascertain the nature of the hearing loss and to verify that it is not reversible by medical intervention. Along with that decision, the otolaryngologist should encourage patients to try amplification, and should refer them to a reputable hearing-aid dispenser. The otolaryngologist should also follow patients to ensure that they receive quality hearing health care.

The role of the audiologist and the hearing-aid dispenser is to assess the individual's communication needs and to select the optimal hearing aid and/or ALDs. Training in the use of the devices, teaching new strategies to meet communication demands, and proper orientation for the amplification devices should be provided. Dispensers should profide frequent follow-up services to ensure that the patients are using their hearing aids satisfactorily.

It is beyond the scope of this chapter to include all the considerations involved in the hearing-aid selection process. Some general considerations follow.

Candidacy for hearing aid or ALDs

Obviously, the individual must have an aidable hearing loss to be considered for amplification devices. In other words, the hearing aid must be able to provide measurable benefits to the patient. From the standpoint of pure-tone audiogram alone, hearing loss from 25 to 100 dB HL is considered aidable. The nature of the hearing loss (that is, conductive ro sensorineural) should be noted, and a decision should be made as to whether the loss can be corrected medically. In the past, hearing aids were worn successfully by patients with primarily conductive hearing loss. With the advances in electronic technology, the majority of today's hearing aids are worn by individuals with sensorineural hearing loss.

Certain hearing loss configurations were once considered poor indicators for amplification. Examples include precipitous hearing loss above 2000 Hz, rising audiogram, and 2-K inverted-V audiogram. With the advances in programmable hearing aids, multichannel hearing aids, high-order active-filter hearing aids, and advanced earmold and ear-hook technology, these hearing loss configurations can now be treated more successfully. Fig. 179-13 summarizes aidable hearing loss configurations.

A diagnostic test that has been used routinely to determine hearing aid candidacy is the word-recognition test. The score on the test gives an indication of the patient's speech understanding ability. However, word-recognition score alone cannot predict the patient's communication performance in the real world. The use of visual and contextual cues could aid in the communication process. Consequently, the word-recognition score should not be used as the only criterion for evaluating the candidacy of a patient for a hearing aid.

The need for and the perceived importance of communication are important factors to consider. A mild hearing loss may not significantly affect a 70-year-old who spends most of the time watching TV or reading the newspaper. On the other hand, the same hearing loss may be significant for someone who is socially active and dependent on hearing acuity. Individuals with visual difficulties may depend more on their hearing than someone without any visual problems. For these individuals, hearing aids must be recommended.

Children, especially those under the age of 12 years, require special considerations beyond the scope of this chapter. Their speech, language, and cognitive development depends on the auditory signals that they hear. Their educational achievement, as well as their social development, are contingent on normal speech and language skills. Current research indicates that children with a hearing loss, even a mild, fluctuating, unilateral hearing loss (between 20 to 40 dBHL) due to recurrent otitis media, could experience a 1- to 2-year delay in educational achievement. Sometimes these children may exhibit behaviors that cause them to be misdiagnosed as mentally retarded, learning disabled, autistic, or behaviorally disruptive. As a primary caretaker for the child's welfare, one has the obligation to diagnose the child's hearing loss as soon as possible, but no later than 6 months after birth. Once a hearing loss has been diagnosed - even a mild hearing loss - one should recommend amplification and refer the child to the appropriate education agency for follow-up services. Hearing loss in children must be treated aggressively. Early identification, appropriate intervention, and strong rehabilitation programs are necessary.

Choice of ear to aid

Monoaural versus binaural

Given that normal hearing individuals hear with two ears, it seems natural that hearing aids should be worn binaurally whenever possible. Fitting a monaural hearing aid in the presence of bilateral hearing loss would still leave behind a unilateral hearing loss.

A complete description of the benefits of binaural hearing can be found in the volumes edited by Libby (Binaural Hearing and Amplification, Zenetron, 1980). The following is a partial list of the reported benefits of binaural hearing.

1. It is necessary for sound localization, that is, the ability to tell direction of a sound source in space.

2. It eliminates the head-shadow (attenuation of high-frequency sound transmitted to the other ear) effect caused by the head.

3. It increases the perception of loudness level by an equivalent of 6 to 10 dB over a monaural listening condition. The implications of this phenomenon are that:

- Patients do not need to turn the volume-control wheel to as high a level to maintain comfortable listening. A lower VC setting is less likely to produce distortion and more likely to result in better sound quality.

- Lower VC setting also means less likelihood for acoustic feedback.

- Lower gain requirement for each hearing aid in the binaural mode means that individuals with severe-to-profound hearing loss who cannot receive enough gain from monaural hearing aid could potentially be helped with binaural hearing aids.

4. It improves speech understanding in quiet and in noise.

5. It improves ease of listening comfort.

6. It creates a feeling of stereophonic listening.

7. It reduces bilateral tinnitus.

8. It reduces the likelihood of auditory deprivation in the unaided ear.

9. It allows the individual to continue to use amplification if one hearing aid malfunctions or a medical condition requires that an aid be kept out of one ear for a while.

Candidates for binaural hearing aids

The previous list of benefits for binaural hearing would suggest that binaural amplification should be the method of choice for all hearing-impaired individuals, regardless of symmetry and degree of hearing loss. This approach differs from the former view that binaural amplification is appropriate only for individuals with symmetric hearing loss and relatively good speech-recognition scores. This change in philosophy is due to the improvement in hearing-aid technology, increased knowledge about the benefits of binaural amplification, and the realization that the speech-recognition score is not the only factor to consider when evaluating hearing-aid benefits. Indeed, my own clinical experience indicates that as many as 85% of hearing-impaired individuals, regardless of the symmetry of their hearing loss, preferred binaural hearing aids over monaural hearing aids at the end of a 30-day cost-free trial period.

Binaural hearing aids may be inappropriate for some individuals. Those with central auditory dysfunction in addition to a hearing loss may not be able to integrate signals from both ears to form a unified perception. These patients complain that they hear two dissimilar sounds in their ears and that they are distressed by the nonintegration. These individuals may benefit from monaural hearing aids only.

Individuals whose word-recognition ability in the better ear is degraded by the use of a hearing aid on the poorer ear may not benefit from the use of binaural hearing aids. Individuals with severe loudness tolerance problems may find the use of binaural hearing aids overwhelming. Some individuals may find the use of binaural hearing aids too "confining" and report a "closed-in" feeling. Some individuals may have difficulty handling two hearing aids. For these individuals, the use of monaural hearing aids, although not optimal, is preferable.

Selection of ear for monaural hearing aid

When a decision is made for monaural hearing aid use in the presence of bilateral hearing loss, one needs to select an ear for amplification. A general guideline is to select the ear that has the best potential for improvement. Typically, speech-understanding ability is used as the criterion, and the ear that has the highest word-recognition score is chosen. When both ears have similar word-recognition scores, the ear that has the greater hearing loss, or the ear that has more conductive component is chosen. The ear with the higher tolerance for loud sounds should be chosen if all else remains the same. Other factors such as physical condition of the ear (for example, drainage, size of ear canal, shape of pinna) and patient preference also should be considered in choosing the ear for amplification.

Contralateral routing of signal (CROS) hearing aid

Individuals with normal hearing in one ear and an unaidable ear (no measurable hearing or word understanding) often miss the conversation if someone is speaking on the side of the unaidable ear because the head attenuates the high-frequency sound as it travels from the side of the unaidable ear to the normal ear (that is, head-shadow effect). To overcome this difficulty, a microphone (in a hearing-aid case) is placed on the side of the unaidable ear. The acoustic signal received on that side is routed to the normal ear for reception. In this case, signals received in the normal ear and the unaidable ear will be heard at the normal ear.

Another version of the CROS aid, and the BiCROS, is used for individuals with one unaidable ear and one aidable ear. It uses two microphones and one receiver. In this version, sound from the unaidable ear is routed to the aidable ear. At the same time, the microphone on the aidable ear also receives sounds on that side. Signals from both sides are amplified and output through the receiver to the aidable ear. The hearing aid on the aidable ear serves as a receiver for sounds from the unaidable ear, and as an independent hearing aid for the aidable ear. Fig. 179-14 shows the microphone and receiver arrangements for CROS and BiCROS hearing aids.

CROS and BiCROS hearing aids can be connected physically (wired) or separated (wireless). The advantage of the wireless CROS is convenience. The advantage of the wired CROS is greater selection among different manufacturers and models. It must be stressed that although CROS and BiCROS hearing aids give the appearance of binaural hearing aids, hearing perception occurs only in the aidable ear. Thus users of CROS and BiCROS hearing aids may not enjoy binaural benefits.

Style of hearing aid

The previous section listed the advantages and disadvantages of each style of hearing aid. It is important to inform the patient of such differences. At the same time, the choice for a particular style depends on a consideration of the patient's hearing loss, the communication environments, and personal preference. Unless it is absolutely prohibitive for the patient to use a particular style of hearing aid, one should respect the patient's preference. A hearing-impaired patient will not use a hearing aid unless it is accepted.

Hearing-aid dispenser consideration

Although it is important to diagnose a hearing loss and rule out any medical contraindications to the use of hearing aids, it is just as important to refer the patient to a reputable hearing-aid dispenser for rehabilitative services. A referral should not be taken lightly. Referring the patient to "buy a hearing aid from any hearing-aid dispenser" sends the message that you are indifferent to the benefits of hearing aids and that you do not care enough for your patient. On the other hand, referring your patient to a specific, reputable dispenser reinforces your patient's belief that you care for his or her welfare. A dispenser who works for the patient's welfare would emphasize to the patient that the referring physician has made a good referral. The following are some considerations in a referral.

Education

Most states require that the hearing-aid dispenser be licensed through written and practical examination. Currently, two groups dispense hearing aids. One group, hearing instrument specialists, learned their skills from established hearing-aid dispensers. The other group, dispensing audiologists, hold a master's degree in audiology. Although their education and experience differ, both groups can be equally effective in providing patient care.

Instrumentation/equipment

The proper fitting of hearing aids requires sophisticated instrumentation. For example, a hearing aid test box is needed to ensure that the recommended hearing aid conforms to the manufacturer's specifications. A probe-microphone unit is needed to ensure that the patient receives the desired amount of amplification from the hearing aid. Other test equipment includes audiometers, impedance bridges, battery drain meters, and earmold modification tools.

Proximity of dispenser to patient

Hearing-aid fitting often requires more than one visit. In addition, it may take several follow-up visits for the patient to adjust to the use of the hearing aid. A patient should be encouraged to visit a qualified dispenser who is geographically convenient for ease of follow-up services.

Personality

The attitude of the dispenser in the hearing-aid selection/fitting process can determine the success of the fitting. A dispenser who is patient, compassionate, and understanding will make the patient feel at ease to disclose the real communication needs. A dispenser who has a sense of humor and who encourages success will make it easier for the patient to learn how to use the hearing aid properly. A dispenser who has a sense of responsibility and commitment to the patient will ensure that the patient is using the hearing aids to its full advantage. Before referring patients to any dispenser, arrange a clinic visit to ensure that the dispenser has these qualities.

The Future of Hearing Aids

The advent of digital technology in the hearing aid field has resulted in a refinement of the devices for use by hearing-impaired individuals. Today, hearing aids can be grouped into three categories according to the technology involved.

Analog hearing aids

Analog aids are the traditional hearing aid. Input signals are transduced by the microphone, amplified and transduced by the loudspeaker. The frequency composition of the signal is affected by manually adjusting the filter settings.

Hybrid hearing aids

Hybrid hearing aids function essentially the same way as analog hearing aids, except that the control of the amplifier and filtering networks is affected digitally. One type of hybrid device is the programmable hearing aid. This device has a wide frequency response that can be adjusted by a computer. Programmable hearing aids are more flexible and can fit individuals with different degrees and configurations of hearing loss.

Another example of a hybrid device is the Zeta Noise Blocker (ZNB), an integrated chip that is housed in an analog hearing aid for the control of background noise.

Digital hearing aids

The main difference between an analog and a digital hearing aid is the component used to process the signal (Fig. 179-15). In an analog hearing aid, the amplifier and its associated filters amplify and shape the signal. In the digital device, the transduced signal (from the microphone) passes of "1" and "0" digits. These digits are then manipulated by a central processing unit (CPU) to a different string of digits. Amplification and filtering of signal are achieved by changing the digits. The processed digits are then passed through a digital-to-analog (D/A) converter before it is transduced by the receiver.

The advantage of digital hearing aids is the unlimited ways that one can manipulate the digital signals. This feature could be useful for signal enhancement, noise reduction, or feedback control. Presently, researchers and manufacturers are investigating ways to apply digital technology for signal modification; however, the widespread use of digital technology in hearing aids may not be possible in the near future. Obstacles that need to be overcome include the power consumption of digital technique, the cosmetics of the device (body processor and behind-the-ear aid), and cost.