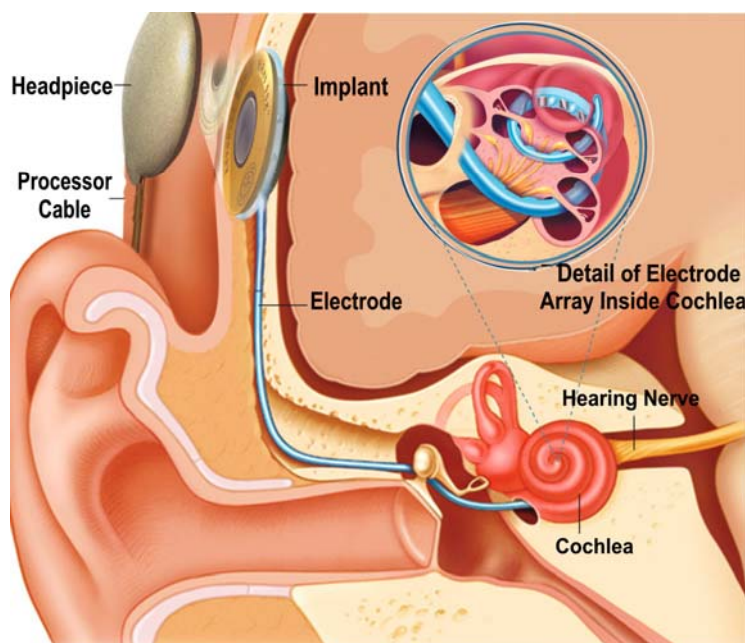


Bilateral Cochlear Implantation in Adults Background and Literature Summary

Introduction

Cochlear implants have been used safely and successfully for over two decades to provide auditory sensation to people with severe to profound sensorineural hearing loss. They work by electrically stimulating the surviving auditory nerve fibers (Figure 1). The basic components include a microphone, an external signal processor, an external transmitter, an internal receiver, and an electrode array implanted in the cochlea. The microphone picks up sounds and transmits them to the external signal processor, which transforms sound into electrical signals. These signals are transmitted to the internal receiver implanted in the temporal bone, which activates the electrodes implanted in the cochlea. Sounds are converted into electrical energy that directly stimulates the auditory nerve, which recognizes this stimulation in much the same way it recognizes normal sounds and sends information along the nerve to the brain, which gives meaning to the sounds.

Figure 1. How a Cochlear Implant Works



A microphone in a headpiece worn behind the ear picks up sound and converts it into an electrical signal that is sent to a small speech processor worn on a belt or behind the ear. A computer chip in the unit converts the signal into an electrical code, which is transmitted to a tiny device surgically implanted under the skin. This device decodes the signal and sends it down electrodes threaded into the cochlea, where it stimulates the auditory nerve.

Source: Advanced Bionics, 2005

Implant performance has improved significantly over the last decade, largely due to improvements in the techniques the speech processor uses to translate pitch, timing, and loudness information into electrical signals.¹ Candidate criteria have also been refined and expanded.

Cochlear implants differ from hearing aids, which amplify sound and therefore can only benefit people with residual hearing who have functioning sensory receptor (hair) cells in the inner ear. The cochlear implant takes the place of these hair cells. Unlike hearing aids, a cochlear implant (CI) has both internal and external components, and requires a surgical procedure to place the internal processor. This procedure usually takes two to four hours and requires an overnight hospital stay.

Cochlear implants historically have been implanted only in one ear. However, people with normal hearing and those with impaired hearing who use acoustic amplification (hearing aids) benefit significantly when

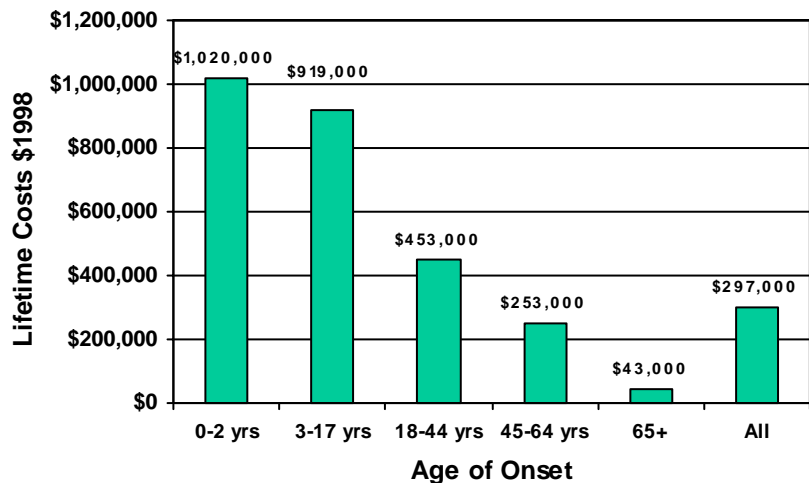
listening with two ears versus one ear. Binaural benefits in everyday listening situations include better speech understanding in noise, improved localization of sound sources, and improved sound quality and clarity. Because the safety and efficacy of unilateral cochlear implantation is well established, there is a growing trend to provide two devices to patients rather than just one. This paper briefly presents background information and reviews recent studies of bilateral implants.

Background

Scope of hearing loss problem. Over 28 million Americans, or about 10 % of the U.S. population, have some hearing loss,² and 464,000 to 738,000 persons are estimated to be severely or profoundly hearing-impaired.³ Sensorineural, or "nerve deafness," that results from damage to tiny cochlear hair cells in the inner ear causes about 85% of hearing impairment. Serious hearing impairments disadvantage individuals and are expensive to society. Only 56% of the severely to profoundly hearing impaired graduate from high school, compared to 81% of the general population, and 5% graduate from college, compared to 13%. Their family incomes are significantly lower, and many cannot work at all. They are also substantially less likely to have comprehensive health insurance.³

While the incidence of severe hearing loss is relatively low, per-person losses are large. Special education, social services, and other resources needed to help deaf people function in a hearing society cost an average of \$297,000 in direct medical and non-medical costs as well as lost productivity (Figure 2).⁴ The National Center on Birth Defects and Developmental Disabilities estimates total lifetime costs for all people with hearing loss born in 2000 will be \$2.1 billion in 2003 dollars.⁵ Hospital outpatient visits, sign language interpreters, and out-of-pocket expenses are additional.⁶

Figure 2. Lifetime Costs of Deafness by Age of Onset



Source: Project Hope, 2000. 1998 dollars.

Many hearing-impaired people are post-lingually deafened adults; that is, those who lost their hearing suddenly or progressively after learning spoken language. For many of these people, cochlear implants are particularly useful because an individual who is accustomed to receiving signals about sound can fill in certain gaps from memory even if the implant's signals to the brain are less refined than those provided by an intact cochlea.⁷ The sooner a person receives an implant following deafness, the greater the likelihood of benefit.⁸

Advantages of binaural hearing. Many cochlear implant users can understand spoken words very well in quiet conditions. However, even the most successful users often have trouble hearing in noisy environments and identifying where sounds are coming from.^{9,10} They also miss out on many other important advantages that normal-hearing people experience from having two ears. Those advantages include:¹¹

- **Safety:** When a person hears with only one ear, inability to locate sound can be dangerous, especially in traffic or in many work environments.
- **Improved understanding:** Binaural hearing helps people sort out and understand individual voices, and to separate speech from competing noise.
- **Wider hearing range:** A voice barely heard at 10 feet with one ear can be heard up to 40 feet away with two ears.

- **Restful listening:** Listening with only one ear is physically tiring and stressful.
- **Better sound identification:** Many noises which sound almost exactly alike when heard with one ear can be identified more easily when heard with two ears.
- **Smother tone quality:** Binaural hearing generally requires less volume, giving a natural sound to voices and music.
- **Hearing with less volume:** Hear more quietly with less background interference.

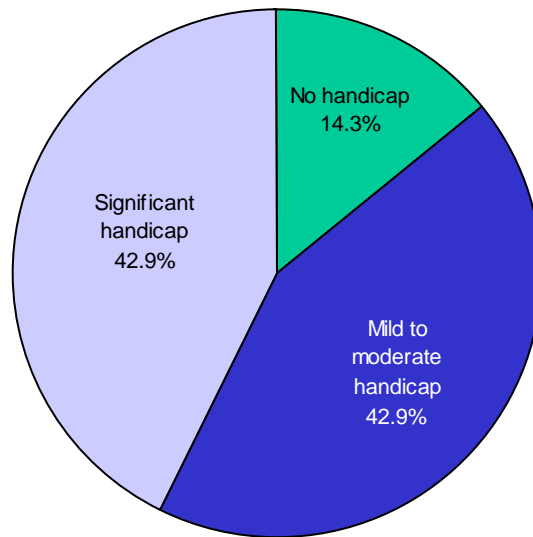
In more scientific language, hearing with both ears—binaurally—has several benefits (often called “the binaural advantage”):

- **Sound localization.** Normal listeners can tell where sound is coming from in the horizontal plane (at ear level) with an accuracy of +/-14 degrees. The brain uses differences in intensity and time between the two ears to determine the location of a sound source. To localize sound in the vertical plane (up and down), or when time and intensity cues between the two ears are ambiguous, spectral (pitch) information is important. The shapes of the outer ear and ear canal change the intensities of all of the pitches arriving at the ear (by reflecting them differently) to determine the location of sounds in the vertical plane.¹²
- **Head shadow benefit.** When listening to speech in noise, the head acts as a sound barrier that makes noise quieter on the side away from the speech. Therefore, when one ear is close to the noise source, adding the other ear (away from the noise) provides a second ear where the speech is louder than the competing noise. The brain can automatically switch to the ear with the better signal-to-noise ratio to take advantage of this effect.¹³
- **Binaural squelch.** When signals and noise come from different directions, the brain separates them by comparing time, intensity, and pitch differences between the two ears. The practical effect is that the brain can suppress signals that the listener does not wish to hear.¹² For example, in a room with many competing voices, the brain can choose to focus on and listen to one speaker among many.¹⁴
- **Binaural summation.** When a person listens with two ears, redundant information from each ear is processed in the brain and the threshold of hearing improves significantly. Sound that is heard binaurally rather than monaurally is perceived to be twice as loud, and the sensitivity to small differences in intensity and frequency increases. Speech perception improves in both quiet and noisy conditions.¹³

Studies of unilateral hearing loss. One of the best ways to understand the difficulty of having only one good ear is to look at studies of people with unilateral hearing loss. Such studies have clearly demonstrated the disadvantages of hearing with only one ear, even if the hearing in the other ear is normal or nearly normal. In one study, 86% of patients with normal hearing in one ear reported mild or greater hearing handicap, indicating “communication and psychosocial problems.”¹⁵ 43% reported significant handicap (Figure 3).

In general, the greater the degree of unilateral hearing loss, the more difficulty an individual will have with sound localization and speech perception.¹⁶ Background noise often interferes with word recognition in both quiet and noisy conditions even when the speech is directed to the good ear. People have reported difficulty hearing and understanding speech even in relatively quiet situations that included background noise such as quiet music (e.g., car radios) or running air conditioners or heaters.¹⁷ Many individuals with severe and profound unilateral impairment have problems at work and in their social lives because of these communication problems, and may need to be treated for depression.¹⁸

Figure 3. Severity of Hearing Handicap in Unilateral Deafness



Those who have unilateral hearing loss or have corrected hearing in only one ear also face predictable difficulties in everyday living and in occupational settings. Like many people with severe bilateral deafness, they may present an increased safety risk while driving because they cannot hear car horns or emergency vehicles or tell where they are, and they may face restrictions in many occupations. There is little agreement about whether these restrictions are necessary, and in some cases they are being challenged in court. In 1999, for example, 1,000 hearing-impaired UPS workers sued United Parcel Service because it refused to let deaf employees drive its trucks. In 2004, a

federal judge ruled that UPS had to evaluate deaf truck drivers individually for ability to drive its smaller trucks. However, hearing-impaired drivers still cannot drive the larger trucks that comprise most of the UPS fleet because commercial drivers of large trucks must meet U.S. Department of Transportation hearing standards.¹⁹ Despite emerging disability law and the broad application of the Americans with Disabilities Act (ADA), serious hearing deficits are and will continue to be a barrier to many occupational activities.

Bilaterally deaf people with only one cochlear implant have the same disadvantages as people with unilateral hearing loss. These may be overcome by implanting both ears. Experience with hearing aids has shown that in many cases of unilateral hearing loss—depending on the extent and cause—a hearing aid placed in the affected ear substantially improves both hearing and functioning and clearly demonstrated the binaural advantage. Similarly, bilateral amplification improved speech recognition, sound localization, and sound quality for individuals with hearing loss in both ears who previously had used only one hearing aid.²⁰

Studies of Bilateral Cochlear Implantation

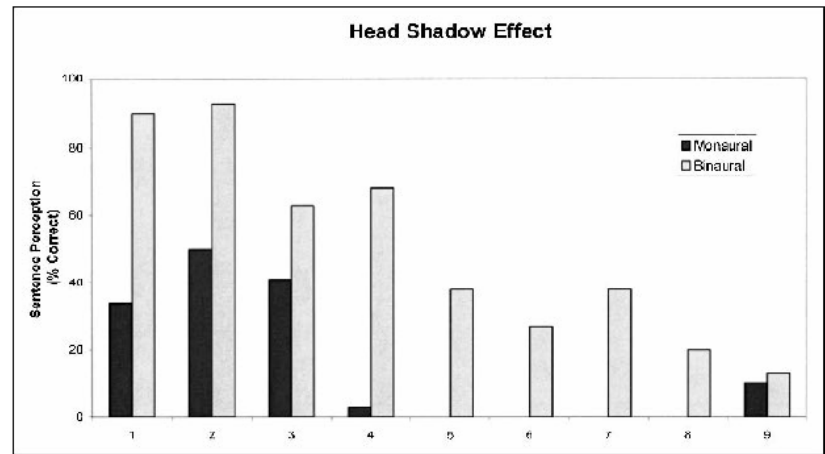
In the mid 1990s, after monolateral cochlear implantation had been proven effective in treating severe to profound deafness, investigators theorized that bilateral CI would be even more effective. Since then, several research centers have studied the benefits of bilateral cochlear implantation in adults and reported results from systematic studies. The University of Iowa,^{21,22} the University of Wisconsin,²³ and the University of Würzburg^{24,25,26,27,28,29} have all published recent studies that examined the effects of bilateral implants on one or more of the binaural advantages discussed above. A thorough technical review of these studies is beyond the scope of this paper, but the findings are highly positive.

Studies indicate that most bilateral implantees have dramatic improvements in head shadow effects (for example, see Figure 4 for magnitude of effect on speech perception in one study of nine patients). They can also localize sound with two implants significantly better than with one implant. Some bilateral implant users show binaural summation and binaural squelch effects. Notably, there have been no reports of worsened speech perception or localization for bilateral vs. unilateral implant use. Moreover, when asked what they preferred, *all* bilateral implant users strongly preferred two implants to using one implant with the better ear alone.^{21,22,23,24,25,27}

One 2004 analysis quantified the benefits of two implants for everyday listening and quality of life.³⁰ 24 patients with unilateral implants were randomized to one of two study groups. One group received a second implant immediately, and the second group received one after 12 months. When everyday listening benefits were assessed with a standard scale, patients with bilateral implants reported better speech understanding in noise, improved clarity and quality of sound, and better spatial hearing in everyday situations than patients with unilateral implants.

The complication rate of bilateral implantation is extremely low. Available data suggest that complications typically associated with cochlear implantation are no greater in patients who receive two implants during the same operation than in patients who receive only one device.¹²

Figure 4. Head Shadow Effect With Monolateral and Bilateral Implant



Source: Müller et al. *Ear and Hearing* 2002;23, 198–206

Technical Advances in Bilateral Cochlear Implantation

The HiResolution™ Bionic Ear System can process full broadband sound with a high level of detail intended to deliver the cues necessary to improve bilateral effects and the binaural advantage. Its input sound-processing capability is designed to capture the wide range of intensities necessary to preserve the loudness relationships required to hear speech in noise. In addition, its high-rate sound sampling is intended to accurately represent the timing cues across all frequencies. Most importantly, the HiRes™ system is designed to faithfully reproduce with high resolution the fine time and intensity differences in the electrical signal delivered to the hearing nerve. In addition, the T-Mic, which is placed into the external ear, allows Auria users to take advantage of head shadow and pinna effects for better speech perception in noise and improved localization. Compared to conventional cochlear implants, these technological advances should enhance the ability to hear with two implants.

Preliminary clinical results from patients who have been implanted with two Bionic Ears at one U.S. research center indicate that HiRes™ sound processing provides bilateral benefit that is superior to bilateral benefit from conventional sound processing. Multicenter studies are further exploring the extent of binaural benefit to recipients of the HiResolution™ Bionic Ear.

Conclusion

The multiple benefits of binaural hearing have been well established. However, as one observer noted, “Although eyeglasses replaced the monocle decades ago, the use of binaural hearing aids has lagged behind.”³¹ Providing good binaural hearing with bilateral cochlear implants is an essential step toward making the hearing-impaired population more productive and improving their quality of life. Technical improvements in signal processing that have been developed and tested are helping to reach this goal today.

Notes

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