Cochlear Implantation in the Twenty-First Century

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Currently, cochlear implantation is a very exciting, expanding, and rapidly changing field of otology. My opinion and earnest hope is that several new developments will take place in the early twenty-first century.

In this article, I focus on the short- versus long-electrode controversy in some detail as it relates to implantation for deafness and then briefly discuss our thoughts and current efforts related to cochlear implantation for the electrical suppression of tinnitus. Let me start with my conclusion, which commonly is viewed as heresy among the orthodox: Patients with single-channel implants can achieve significant open-set speech discrimination. Momentarily, we will discuss the theory and data that support this concept. Clearly, multichannel devices also work. However, as we shall see, they do so at a significant cost to the patient and by that I mean not merely financial.

Through the International Center for Otologic Training and my interest in implants, I have developed a close relationship with Bill House. He has an infectious personality and is an ingenious humanitarian who still espouses the single-channel implant theory despite current orthodoxy. I repeatedly read Bill's three monographs [1-3] on the subject, and increasingly they made sense to me. His theory was plausible but, for me, the proof demanded data. So, I committed four trips to Los Angeles to review and study his data but, more importantly, to interview and videotape his patients.

Now I briefly will review his theory and supportive data and then will show you videotapes of my interviews with these patients. At the conclusion of this presentation I hope that you will begin to evolve your position on this controversy.

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THEORY

The theory behind the use of multiple electrodes in cochlear implants is based on Von Bekesy's tonotopic theory, according to which the normally functioning cochlea mechanically sorts sounds by their frequency: high tones closer to the round window and low tones closer to the apex. In essence, the cochlea is like a piano, and the critical event should be to press the keys at the right spot to initiate the proper tone or frequency. However, does the tonotopic theory apply to the damaged—as opposed to the normal—cochlea?

In fact, several clinicopathological studies of temporal bones of deceased implant patients have shown that very few of them have any residual dendrites in the basilar membrane [4]. Because dendrites are absent, focusing our electrical current on an area of the basilar membrane that cannot respond to that stimulation makes no sense. Simply put, the piano keys are missing.

Furthermore, the geometry required by the tonotopic theory is not satisfied by either 6-mm or 25-mm electrodes. The 25-mm electrode, when inserted into the scala tympani, anatomically will extend from the 20,000-Hz region of the basilar membrane at the round window up to approximately the 1,500-Hz area. By contrast, the short 6-mm electrode extends up to only approximately the 4,000-Hz area. Tones below 2,000 Hz should, therefore, be impossible with either device but, in fact, the audiograms of implant patients do not differ on the basis of the length of electrode used. Tone perception down to 250 Hz has been demonstrated for both implants.

If the tonotopic theory were valid for cochlear implants, we would expect small bipolar electrical fields to be most efficient at precisely focusing stimulation along the basilar membrane. Indeed, one might think large fields should not work at all, as in no way could the ear sort through the frequencies in the signals that are being presented so generally to the cochlea. To do so would be like pressing all the keys on the piano simultaneously.

In contrast to what we might expect, closely paired electrodes have been shown repeatedly to be less efficient and to require higher levels of current to achieve threshold. However, when we stimulate the cochlea generally, without regard to frequency placement along the basilar membrane, current requirements are reduced; consequently, battery life is increased. Forcing more current to flow between the closely paired electrodes apparently causes the electrical field to grow large enough to spill over and stimulate the cochlea more generally.

This finding and the previously demonstrated anatomical evidence would imply that the most probable site of stimulation is the spiral ganglion cell body within the modiolus. This theory now is accepted commonly. Thus, the tonotopic theory appears to be invalid for the damaged cochlea, on the basis of the aforementioned clinical data and supportive anatomical investigation.

How then do cochlear implants work? Some insight is gained from the work of Kiang [5], a neurophysiologist from Harvard, who, during the 1960s, obtained numerous recordings from type 1 auditory neurons in cats who were exposed to frequency sweeps of sound at varying intensities. Kiang found that each fiber was in fact tuned to a specific or characteristic frequency at the lowest intensity or threshold of stimulation. When these studies were repeated where hair cell destruction was identified histologically, the areas of destruction did not respond to sound, but they would respond to electrical currents applied to the bony capsule of the cochlea. The resultant tuning curves for a given intensity of electrical current were much broader, and the threshold or the characteristic frequency was increased.

Thus, cochlear implantation appears to replace the lost alternating current or cochlear microphonic that ordinarily is produced by the inner hair cells. As Kiang's studies have shown, as long as all frequencies of sound (e.g., a sample of speech) are introduced at sufficient intensity to be above a given spiral ganglion cell's threshold, that spiral ganglion cell will send a signal to the brain that it has been stimulated at its characteristic frequency. In essence, the spiral ganglion cell listens to what it wants to hear.

COMPARATIVE DATA

No valid comparative data to date relate the performance of the AllHear device to current multichannel technology. However, absence of evidence does not necessarily mean evidence of absence.

The often-cited 1993 study by Cohen [6] compared the 3M Vienna device (3M Corporation, Minneapolis, U.S.A.), an "Edsel," to the current Nucleus (Cochlear Corporation, Melbourne, Australia) and Ineraid (Smith-Nephew, Memphis, U.S.A.) multichannel devices, the Ford Tauruses of that day. Although this study is considered a landmark demonstrating superiority of multichannel devices, it was an apples-and-oranges comparison. It compared the superior sound-processing strategies of the then-current multichannel devices to the non-compressed-amplitude–modulated analog signals of the 3M device, which at that time did not have high-frequency representation beyond 3,000 Hz.

However, the main shortcoming of this and all current comparative implant studies is that we have been measuring patient performance rather than implant performance. Patient performance depends on myriad individual and cultural factors reflecting patient skills, talents, native intelligence, previous exposure to speech, educational background, and the like. Controlling these factors is difficult; they not only introduce contaminating errors but mask the contribution of the implant. This type of comparison is analogous to establishing the superiority of a tennis shoe by seeing who wins a foot race. Herschel Walker will always outrun me regardless of what shoe he is wearing.

If we want to measure the implant, we might look at the articulation index, which is an easy and established method of quantifying the possibility of understanding speech on the basis of the audiogram. The articulation index employs a series of 100 numbers placed on a conventional audiogram in a shaded area that represents the average speech spectrum or "speech banana."

The audiogram is plotted, and the numbers below the audiogram are summed, forming the index. The higher the index, the better the ability to hear critical phonemes and the better the sound perception; hence, the better will be speech performance. In fact, this correlation has been shown repeatedly for speech perception ability in deaf patients with hearing aids and, recently, cochlear implants [1,7].

CONCLUSION

From this discussion, it is evident that long electrodes are neither necessary nor desirable. Rather, refining the sound-processing strategies is the way to improve auditory success with implants in the twenty-first century.

The AllHear implant is simple and convenient. It is not married to any complex internal hardware; its energy consumption is more favorable; and it is thus more practical and widely available globally for the rehabilitation of those afflicted with deafness.

Beyond a doubt, the multichannel devices work, their sound-processing strategies have improved over time and, for the deaf patient, any implant is better than none. However, complexity of electrode array begets complexity of sound processing.

One can cause the long electrode to deliver appropriate sound information, despite the invalidity of the aforementioned tonotopic theory for the damaged cochlea. However, the sound must be filtered, mapped, pulsed at rapid rates for fusion by central centers, and interleaved to avoid channel-to-channel interaction and distortion. All this, in the final analysis, is unnecessary and costly. Most tragic and ironic, the long electrode damages residual hearing that is critically important when we consider future diverse applications of cochlear implants, such as the electrical suppression of tinnitus and assistive devices for ski-slope high-frequency losses.

The current discussion is really about a conflict between clinical observation and theory. What occurs in the lives of these single-channel implant patients (whom you have witnessed) is at odds with current orthodoxy in the field of cochlear implantation. Clearly, there is more than one way to skin this cat. At stake are 25 million profoundly deaf people throughout the world, the vast majority of whom cannot possibly afford the expensive technology of multichannel devices.

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