

ELECTRICAL STIMULATION OF RESIDUAL HEARING IN THE IMPLANTED COCHLEA

G. M. CLARK, PHD, FRACS; K. I. MCANALLY, PHD; R. C. BLACK, PHD; R. K. SHEPHERD, PHD

From the Human Communication Research Centre and the Department of Otolaryngology, University of Melbourne, and the Cooperative Research Centre for Cochlear Implant, Speech and Hearing Research, Melbourne, Australia.

The average profoundly deaf person using a cochlear implant can now understand more speech than some severely to profoundly deaf people who use a hearing aid. For this reason there will be an increasing need to consider implanting people with residual hearing. In many of these people there could be significant hearing in the operated ear, as a majority of severely to profoundly deaf people are likely to have a symmetrical hearing loss. When three frequency average hearing thresholds were measured on 219 pensioners from the Australian National Acoustic Laboratories (H. Dillon, unpublished findings), 64% had less than a 10-dB difference between thresholds in each ear (Fig 1).

In severely to profoundly deaf people it would be helpful to know whether residual hair cells can be preserved in the implanted ear, and how best to excite these hair cells. This knowledge could lead to the development of a speech-processing strategy that would not only stimulate auditory nerve fibers directly, but stimulate residual hair cells as well. Electrical stimulation of hair cells is called electrophonic hearing.

We have demonstrated histologically the preservation of hair cells in the implanted cochlea in a number of studies¹⁻⁵ (also Shepherd et al, unpublished observations). These studies have shown that hair cells are preserved apical to scala tympani arrays in cats and monkeys with and without electrical stimulation, unless there is infection or marked trauma. We have also demonstrated in physiological and psychophysical studies in the experimental animal that functioning hair cells are present after cochlear implantation.^{2,6-8} A psychophysical study⁶ on experimental animals showed that electrophonic hearing could be induced in the chronically im-

planted animal at least up to 400 Hz. Above this frequency there was loss of hair cells due to surgical trauma. In addition, research on acute animal preparations,⁷ using brain stem response audiometry (ABR), indicated first that if implantation was carried out gently, without loss of perilymph, post-operative tone pip thresholds were within 10 dB of preoperative values. Second, it was found that click-evoked ABR-derived responses exhibited a normal latency-frequency function following implantation. This indicates that implantation per se does not disturb the frequency-place mechanics of the basilar membrane. In addition, electrical stimulation produced electrophonic hearing at low current levels, and the response grew slowly with increasing current intensity before a more rapid growth due to direct stimulation of the auditory

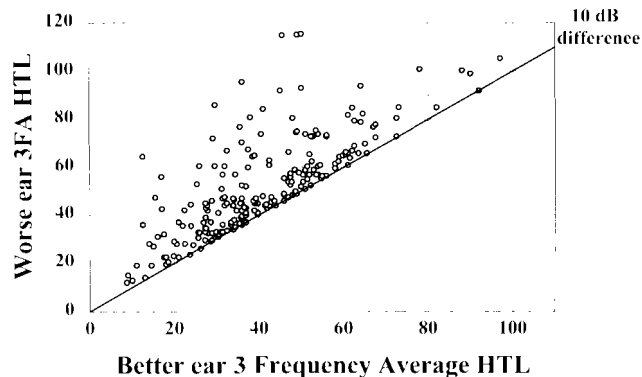


Fig 1. Three frequency average (FA) hearing threshold levels (HTLs) for better and worse ears in 219 pensioners from National Acoustic Laboratories (NAL). Data plotted by H. Dillon (unpublished findings).

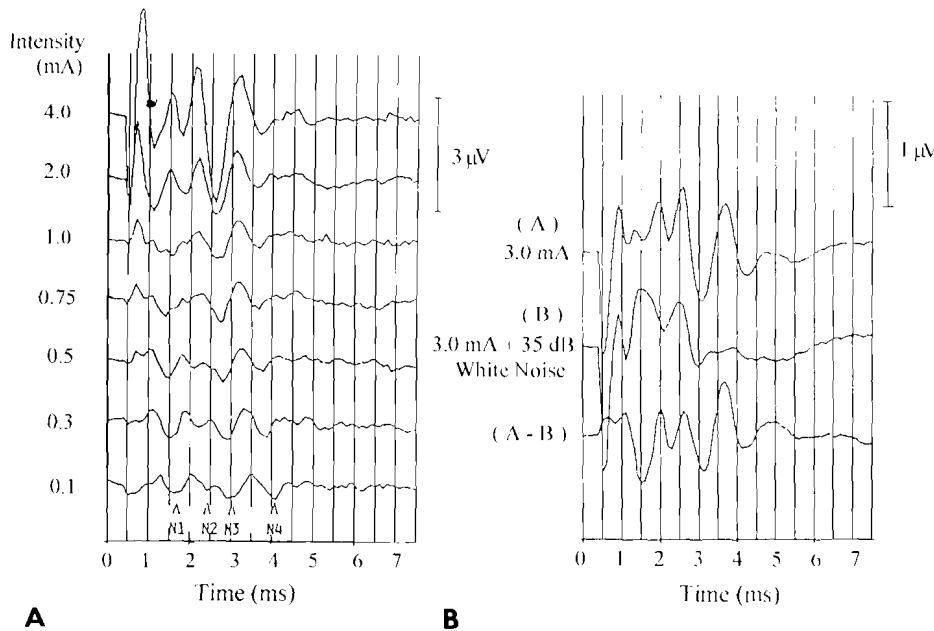


Fig 2. Electrically evoked auditory brain stem responses. A) For increasing current intensities. B) With white noise.

nerve. At higher intensities the electrophonic component could be masked from the response (Fig 2). Another important finding was that when the current intensity was increased the derived brain stem response from the cochlear region adjacent to the electrode was similar to that for direct electrical stimulation, but the responses in other bands were electrophonic (Fig 3).

Although the ABR study showed that electrophonic responses were induced at sites remote from the electrode array, more research was needed to see how they were generated. In particular, were they due to direct stimulation of inner hair cells by the spread of current along the cochlea, or due to indirect stimulation by the propagation of a traveling wave arising near the electrodes? In the latter case, was a basilar membrane traveling wave produced by direct excitation of outer hair cells near the electrode array, or by electromechani-

cal transduction?

The first question examined was, Is electrophonic hearing due to direct stimulation of the inner and outer hair cells from the distant spread of current within the cochlea? This was investigated by masking acoustic probes with electrical stimuli presented at different rates and intensities. If direct stimulation of inner and outer hair cells occurred, then the degree of masking would decrease with current spread along the cochlea and be less for lower probe frequencies.

The masking results⁸ using sinusoidal monopolar electrical stimuli at the round window showed peaks of masking at the probe frequencies (eg, 4 kHz). As the degree of masking for different stimulus rates did not decrease with a decrease in the probe frequency, the results suggest that electrophonic hearing is due to the propagation of a wave along the basilar

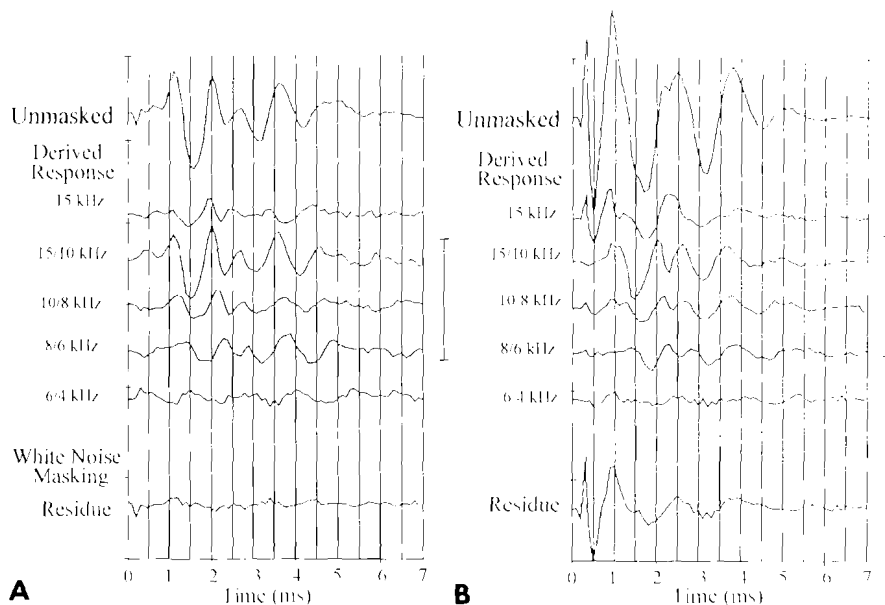


Fig 3. Derived auditory brain stem responses. A) For stimuli at 1.0 mA. All responses are electrophonic with total masking for white noise. B) For stimuli at 1.2 mA. Response for region adjacent to stimulus electrode (>15 kHz) is due to direct nerve stimulation with electrophonic responses in all other bands.

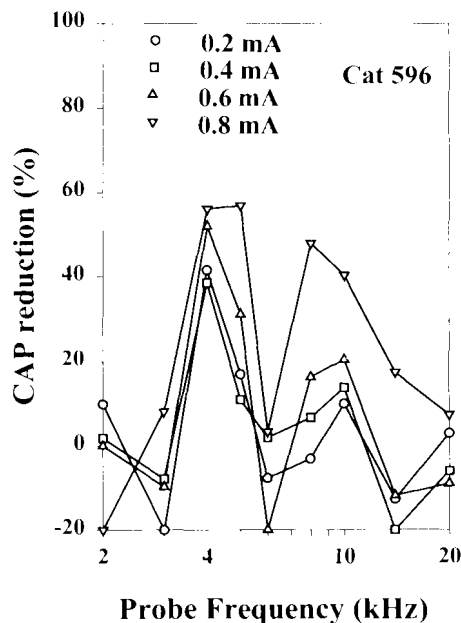


Fig 4. Degree of masking of compound action potential (CAP) from pulse stimulus as function of probe frequency for monopolar round window electrical masker stimulus of 4,000 pulses per second.

membrane, and not due to direct stimulation of inner or outer hair cells (Fig 4).

To be sure that electrophonic hearing was due to the propagation of a wave along the basilar membrane, we carried out a similar study using intracochlear bipolar stimulation, because the current spread is more restricted than for monopolar round window stimulation. Again the masking of the probe was maximal when the probe frequency was the same as the rate of the masker.

The second question examined was: Is electrophonic hearing due to local excitation of the outer hair cells, or electromechanical stimulation of the basilar membrane? To help answer these questions we repeated the masking study after damaging the hair cells in the region of the electrode by overstim-

ulation with a 10-kHz tone. The results showed there was little change to the peak of masking after overstimulation. This suggests that electrophonic hearing is due not to direct stimulation of outer hair cells, but to an electromechanical transduction process.

The above studies on the mechanisms of electrophonic hearing used sinusoidal electrical stimuli. With cochlear implants, however, it is preferable to use pulsatile stimuli. With these stimuli more research is still needed, however, to determine the energy transfer to the low- and middle-frequency regions of the cochlea from an electrode in the basal turn. This is particularly important when the patient has high thresholds in the low and middle frequencies, as more energy will be needed to excite the hair cells than for normal hearing.

REFERENCES

1. Shepherd RK, Clark GM, Black RC, Patrick JF. The histopathological effects of chronic electrical stimulation of the cat cochlea. *J Laryngol Otol* 1983;97:333-41.
2. Shepherd RK, Clark GM, Black RC. Chronic electrical stimulation of the auditory nerve in cats. Physiological and histopathological results. *Acta Otolaryngol [Suppl] (Stockh)* 1983(suppl 399):19-31.
3. Ni D, Shepherd RK, Seldon HL, Xu S, Clark GM, Millard RE. Cochlear pathology following chronic electrical stimulation of the auditory nerve I: Normal hearing kittens. *Hear Res* 1992;62:63-81.
4. Shepherd RK, Xu J, Millard RE, Clark GM. Chronic electrical stimulation of the auditory nerve at high stimulus rates: preliminary results. *Aust J Otolaryngol* 1994;1:453.
5. Shepherd RK, Xu SA, Clark GM, Pyman BC. Cochlear histopathology following long-term electrode implantation and re-implantation in the monkey. *Am J Otol* 1995;16:186-99.
6. Clark GM, Kranz HG, Minas JG. Behavioural thresholds in the cat to frequency modulated sound and electrical stimulation of the auditory nerve. *Exp Neurol* 1973;41:190-200.
7. Black RC, Clark GM, O'Leary SJ, Walters C. Intracochlear electrical stimulation of normal and deaf cats investigated using brainstem response audiometry. *Acta Otolaryngol [Suppl] (Stockh)* 1983(suppl 399):5-17.
8. McAnally KI, Clark GM, Syka J. Hair cell mediated responses of the auditory nerve to sinusoidal electrical stimulation of the cochlea in the cat. *Hear Res* 1993;67:55-68.



Minerva Access is the Institutional Repository of The University of Melbourne

Author/s:

Clark, Graeme M.; McAnally, K. I.; Black, R. C.; Shepherd, R. K.

Title:

Electrical stimulation of residual hearing in the implanted cochlea

Date:

1995

Citation:

Clark, G. M., McAnally, K. I., Black, R. C., & Shepherd, R. K. (1995). Electrical stimulation of residual hearing in the implanted cochlea. *Annals of Otology, Rhinology & Laryngology*, 104(suppl.166), 111-113.

Persistent Link:

<http://hdl.handle.net/11343/27422>

File Description:

Electrical stimulation of residual hearing in the implanted cochlea