A Multiple-Electrode Cochlear Implant


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Interest in artificially stimulating the auditory nerve electrically for sensori-neural deafness was first sparked off by Volta in the 18th century. Count Volta, who was the first to develop the electric battery, connected up a number of his batteries to two metal rods which he inserted into his ears. Having placed the rods in his ears he pressed the switch and received "une secousse dans la tete" and perceived a noise like "the boiling of thick soup".

During the years that have followed, a number of workers have carried out studies on the effects of electrical stimulation of the cochlea and auditory nerve. Some of the first people concerned were Duchenne of Boulogne, Brenner, Gersuni and Volokov, Stevens and Jones and others. The first direct stimulation of the auditory nerve in man was carried out by Lundberg in 1950 and later by Djurno and Eyrles from Paris in 1957. The first multiple electrode stimulation reported in man was by Doyle, Doyle and Turnbull in 1964 and by Simmons et al, 1965. Subsequently, reports of electrical stimulation have been made by Michelson, House, Chouard, Hansen and others.

Along with these patient studies there has been a great increase in our understanding of how the cochlea functions and how speech is perceived. These basic studies indicate that the best chance of enabling a totally deaf patient to understand speech is by multiple-electrode stimulation of the auditory nerve fibres.

To do this effectively requires the implantation of a receiver-stimulator device which needs to contain the equivalent of 6,000 radio valves. Using radio valves or transistors this would not have been possible because of their large size. It was not, however, till we had the development of the integrated circuit that the implantation of a receiver-stimulator device in a patient became a real possibility.

As a result of the development in integrated circuit technology, we have constructed a
FIGURE 2A (Clark et al. 1979)
The posterior skin flap and elevation of the two inferiorly based fascial flaps to expose the mastoid process.

FIGURE 2B
The mastoid exenteration, creation of bed for receiver-stimulator, and posterior tympanotomy with exposure of the round window membrane.

FIGURE 3A (Clark et al. 1979)
The receiver-stimulator device in place.

FIGURE 3B
The fascial flaps sutured in place over the implanted receiver-stimulator device.
receiver-stimulator unit for patient implantation and this is shown in Fig. 1A, next to a 20 cent piece for comparison of size. The squares are integrated circuit chips and the circuitry that goes into just one of those is shown in Fig. 1B.

After rigorous packaging and testing procedures the receiver-stimulator device was made ready for implantation in patients. In August 1978 we implanted our first patient who was a 48 year old male who lost his hearing completely following a head injury eighteen months previously. Polytomes of the temporal bone and electrical stimulation of the promontory indicated that the hearing loss was due to concussion of the cochlea and not transection of the auditory nerve.

The stages in the surgery (Clark et al, 1979) are illustrated in Figs. 2 and 3. An invented U-shaped flap is raised behind the ear to expose the mastoid process and two inferiorly based flaps of fascia are created. A posterior tympanotomy is performed to expose the round window and a bed for the receiver-stimulator is drilled in the mastoid. The electrode array is inserted into the cochlea through the round window and receiver-stimulator placed in its bed. It is then covered by two fascial flaps and the wound closed. Fig. 4A shows the patient as he appeared two weeks post-operatively, and Fig. 4B as he appears now.

Since the operation we have been carrying out a series of psychophysical tests to examine the performance of the individual electrodes acting in isolation and together. When we have completed collating and analysing this data we should be in a better position to design a real-time speech-processor unit that is portable and can transmit information through the skin by radio waves to the underlying receiver-stimulator unit.

The psychophysical tests that we have been carrying out include those to determine the thresholds and threshold ranges for the electrodes, loudness estimates and pitch scaling. Fig. 5 shows the thresholds for the 9 electrodes at pulse rates of 200 pps and 1000 pps (Tong et al, 1979). There is some variation in the threshold with electrode position, and quite a significant reduction in threshold with higher rates of stimulation. These thresholds have remained reasonably stable. Fig. 6 shows the loudness estimates for electrodes 7 and 9 compared to sound, and you will note the rapid increase in sensation with small changes in current. Fig. 7 shows the pitch estimates for different electrodes and rates of stimulation. Notice that there is also a rapid increase in pitch perceived with rate of stimulation so that at 50 pulses per second it is equivalent to a sound of 50 Hz and at 200 pulses/second to 3000 Hz. There is also a

**FIGURE 4A** (Clark et al, 1979)
A photograph of the patient two weeks following the implantation of the multiple-electrode cochlear implant.

**FIGURE 4B**
A photograph of the patient during current test session.
change in pitch with the electrode stimulated as would be expected on a tonotopic organisational basis.

One of the most interesting results is that the patient can perceive vowel-like sounds when stimulating different electrodes, and these can be shifted to others by varying their duration or rate of stimulation. This is illustrated in Fig. 8. This shows that low frequency electrodes produced an /ɛ/ sound as in “egg”. The higher ones produced an /ɪ/ sound as in “sit”. The electrodes in the region of the round window produced quite a low tone sensation and an /ɨ/ sound as in “rod” could be produced. This electrode was shown on a post-operative X-ray to be close to the round window, and the low pitch sensation induced could have resulted from an extra-cochlear spread of current to low frequency nerve fibres. These results with electrical stimulation are consistent with acoustic phonetic studies (Tong et al., 1979) that there is a correspondence between the pitch of a sound and the vowel generated. It is also of interest to notice in these results that an /ɪ/ sound can be shifted to an /ɨ/ sound as in “seat” and an /ɨ/ to an /o/ as in “cord”. These results are again consistent with changes that can be produced by sound.

Finally, stimulating two electrodes together can blend the sensations and produce an intermediate vowel. For example, two
electrodes producing the /ɪ/ and /ɪ/ sounds together produce an /ʌ/ sound as in "hut".

These results then suggest that the most appropriate design for the next stage speech processor should be a formant vocoder or one that extracts out the formants for vowels and consonants and this is being proceeded with at the moment.

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REFERENCES


FIGURE 8
The vowel-like sensations produced by different parameters of electrical stimulation of the implanted electrodes.
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