

# IMPEDANCE MEASUREMENT OF THE NUCLEUS 22-ELECTRODE ARRAY IN PATIENTS

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## INTRODUCTION

By means of a prototype 22-electrode cochlear implant with a telemetry ability, electrode voltage and impedances have been measured in three patients over a 2-month period. A simple electrical model of the electrode-tissue interface is described to explain the results.

## SYSTEM OVERVIEW

The telemetry system is shown in Fig 1. It consists of an IBM PC with an interface card, which communicates over a transcutaneous radio frequency link with a prototype 22-electrode implant. The interface card generates a signal containing stimulus and telemetry commands for the implant.

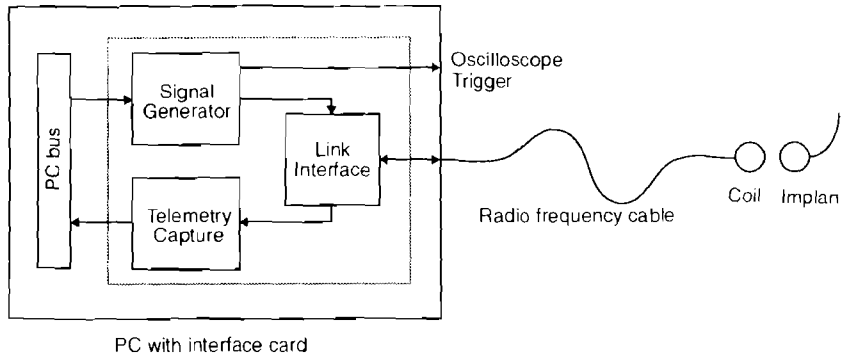


Fig 1. Telemetry system. PC — personal computer.

The implant performs the required stimulation and measurements and transmits the results back to the interface card through the link. The card then detects the telemetry pulses and they are recorded by software. A trigger signal for an oscilloscope is also provided.

**ELECTRODE IMPEDANCE MODEL**

Figure 2A shows the three-element model that is normally used to represent the impedance between a pair of electrodes in tissue.<sup>1</sup> The bulk resistance ( $R_{bulk}$ ) is associated with the substance between the two electrodes. This substance is assumed to be an ionic medium and therefore to behave as a pure resistance at the frequencies of interest here. In contrast, the surface capacitance ( $C_{surf}$ ) is associated with the contact between the electrodes and the tissue. Its value is determined by factors such as geometric electrode surface area, surface roughness, and the amount and nature of absorbed chemical species. The leakage resistance ( $R_{leak}$ ) attempts to model the redox reactions occurring at the electrode surface that involve charge transfer between the electrode and the tissue. The rate of these reactions (and therefore the current across the interface) is proportional to the logarithm of the voltage across the interface, so the leakage would probably be better represented by parallel zener diodes than a resistor. To minimize the effect of  $R_{leak}$  on the measurements, a low stimulation current (100  $\mu A$ ) was used so that the voltage across the interface never reached a value at which significant charge transfer occurred.

With a simplified electrode model, and with  $R_{leak}$  assumed to be infinity, the electrode voltage waveform resulting from

an applied biphasic current pulse is shown in Fig 2B. The voltages of interest can be expressed as

$$(1) \quad V_0 = I_{stim} \times R_{bulk}$$

$$(2) \quad V_1 = V_0 + I_{stim} \times T_p / C_{surf}$$

where  $I_{stim}$  is the amplitude of the stimulation current, and  $T_p$  is the phase duration.  $V_0$  is the initial electrode voltage and depends on the bulk resistance  $R_{bulk}$ .  $V_1$  is the final electrode voltage, at the end of phase 1, with the increase in voltage due to the capacitance  $C_{surf}$  charging up. This is the largest voltage that appears between the electrodes and so determines whether the current source is able to supply the specified current. The effective electrode impedance is then defined<sup>2</sup>:

$$(3) \quad Z = V_1 / I_{stim}$$

$$= R_{bulk} + T_p / C_{surf}$$

This effective impedance combines both the surface and bulk properties into a single parameter with familiar units (ohms), but it does depend on the pulse width. To obtain  $R_{bulk}$  and  $C_{surf}$  separately requires more than one voltage measurement during the pulse.

**CLINICAL RESULTS**

Results are reported here from three patients in Melbourne. The measurements were taken with a bipolar stimulus amplitude of 100  $\mu A$  and a pulse width of 50 microseconds per phase (except where noted), at a rate of 250 Hz, which was below threshold for each patient. Figure 3 shows the final

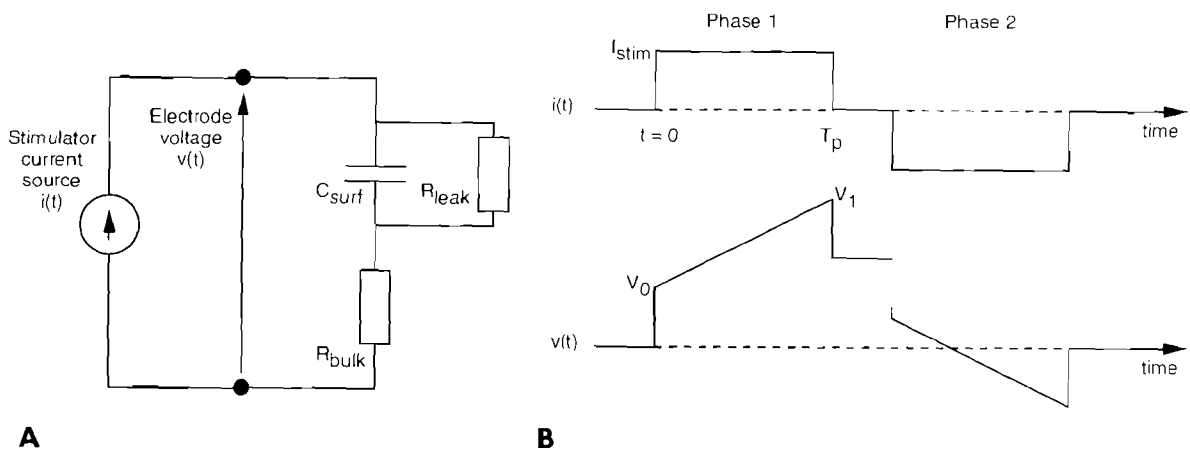


Fig 2. A) Electrode impedance model. B) Electrode current and voltage waveforms.

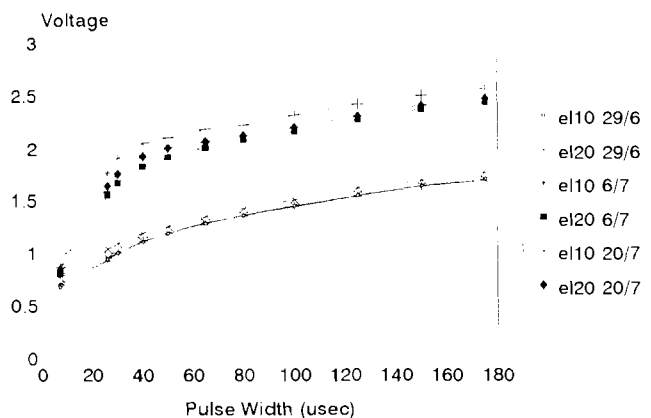


Fig 3. (Patient EH) Final electrode voltage for different pulse widths with bipolar stimulation electrodes 10 and 20.

electrode voltage ( $V_1$ ) as a function of pulse width ( $T_p$ ), for electrodes 10 and 20 of patient EH on three occasions. This effectively demonstrates the entire voltage waveform, and is in general agreement with the model, except that the initial voltage rise is not instantaneous. The surface capacitance  $C_{surf}$  can be calculated, from the slope of the waveform in the linear section, to be about 30 nanofarad for both electrodes (60 nanofarad at each electrode-tissue interface). The initial electrode voltage ( $V_0$ ) can be obtained by extrapolating from the linear section back to time zero, and is about 1.1 V for

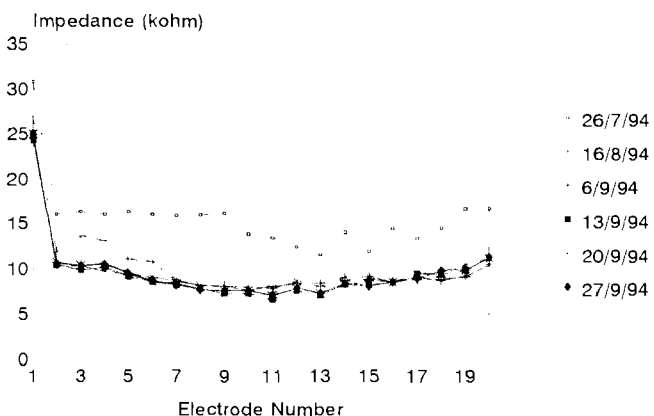
electrode 10 and 1.8 V for electrode 20, giving bulk resistances of about 11 k $\Omega$  and 18 k $\Omega$ , respectively.

Figure 4A shows the effective impedances measured for patient BL on six occasions, beginning with start-up (2 weeks after implantation). The impedances are fairly constant across the array, except for electrode 1, which has roughly twice the impedance of the rest. It was later verified by x-ray study that electrode 1 was outside the cochlea. The impedances had dropped markedly by the second session, 3 weeks later, some to half of the start-up values. After a further 3 weeks the impedances appeared to have settled to around 7 to 10 k $\Omega$ , with very little subsequent change. This time variation is better shown in Fig 4B.

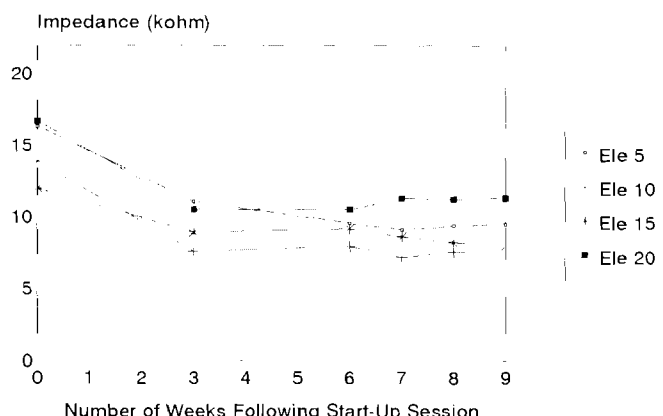
Patient LM shows much the same trend (Fig 4C,D), with most impedances decreasing for the first 4 weeks after start-up, then remaining constant at values similar to those of BL. Some of the central electrodes were stable from start-up onward.

CONCLUSION

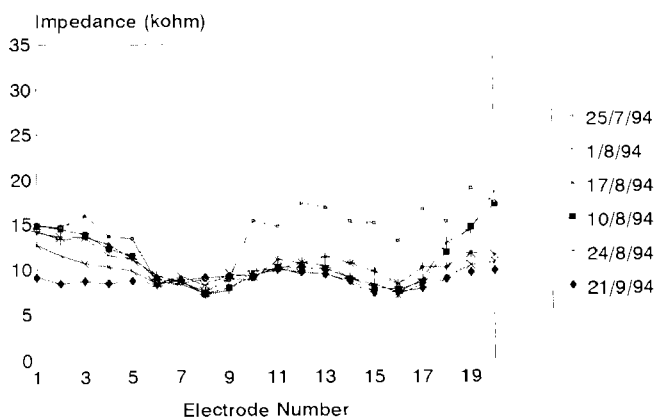
A research system for performing electrode voltage and impedance measurements with patients has been developed. The results are consistent with a simple electrical model of the electrode-tissue interface. In these preliminary results, the impedances dropped markedly in the first few weeks after implantation, then reached a steady value. There was little



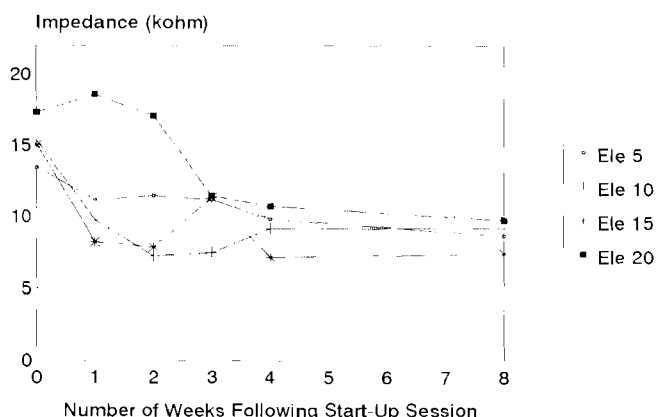
A



B



C



D

Fig 4. Clinical results. A) (Patient BL) Effective electrode impedance, bipolar stimulation. B) (Patient BL) Impedance changes over time, bipolar stimulation. C) (Patient LM) Effective electrode impedance, bipolar stimulation. D) (Patient LM) Impedance changes over time, bipolar stimulation.

variation in the final impedances across the array, and one unusually high value had clinical significance.

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