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ELECTRICAL IMPEDANCE OF THE COCHLEAR IMPLANT LUBRICANTS HYALURONIC ACID, OXYCELLULOSE, AND GLYCERIN

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Hyaluronic acid (Healon), oxycellulose (hydroxypropyl methylcellulose), and glycerin are lubricants used in cochlear implant surgery for atraumatic deep insertion of the electrode array into the scala tympani. The electrical impedances of these three lubricants were measured to assess possible effects on intraoperative evoked response measurements, such as the electrically evoked stapedius reflex and auditory brain stem response. The impedances of hyaluronic acid, oxycellulose, and saline were very similar and independent of frequency (20 Hz to 1 MHz). Glycerin had an excessively high impedance at low frequencies. A film of hyaluronic acid or oxycellulose around the electrode array immersed in saline did not have any measurable effect on the impedance; a film of glycerin resulted in a strongly reactive polarized layer. However, neither the far-field current spread nor the impedance between stimulated electrodes was affected by any of the lubricants applied as a thin film. This suggests that none of these lubricants affect intraoperative responses, when applied as a thin film.

KEY WORDS — cochlear implant, electrical resistivity, evoked responses, impedance, lubricative substances.

INTRODUCTION

In recent years, hyaluronic acid (Healon), oxycellulose (hydroxypropyl methylcellulose), and glycerin have been proposed as lubricants for cochlear implant surgery.^{1,2} These fluids serve to facilitate the atraumatic deep insertion of the cochlear implant electrode array into the scala tympani of the cochlea. Trauma to the spiral ligament and Reissner's membrane can occur easily, especially at the end of the basal turn,³ possibly damaging neural elements and causing secondary reactive osseous formation.⁴ Excessive mechanical resistance to the insertion due to obstructions may also damage the electrode array. It can be expected that deep insertion of the electrode array beyond the basal turn will result in more natural place-pitch mapping. Furthermore, incomplete insertion implies fewer usable electrodes and less recruitment of surviving spiral ganglion cells.² For the 22-electrode Cochlear Nucleus implant device, it has been established that when the apical electrodes are not used for stimulation, implant performance is poorer, on average, than when the medial or basal electrodes are not used.⁵ This finding underlines the need for deep insertion.

According to Donnelly et al,⁶ hyaluronic acid does not affect the hearing thresholds of implanted cats with normal hearing; in the same study, the use of hyaluronic acid enabled deeper insertion into 6 fresh

human temporal bones than in 22 patients implanted without the use of hyaluronic acid. Roland et al² found that an intracochlear injection of hyaluronic acid, glycerin, or oxycellulose did not have any effect on the spiral ganglion neurocyte count in guinea pigs 8 weeks after the injection. The dendrite and axon histology was also well preserved. In some animals, the acoustically evoked compound action potential was reduced in amplitude immediately after the injection of glycerin. Hyaluronic acid was the only substance that did not cause a pressure drop in the cochlear fluid (hydrops). All three substances were considered suitable for cochlear implantation, although oxycellulose was said to be nonmetabolized.

No data are available on the electrical properties of these lubricants. Many implant centers measure electrically elicited stapedius reflex and auditory brain stem thresholds in young children immediately after insertion of the electrode array. These thresholds are used as objective indications of the postoperative threshold and comfort levels needed for fitting the speech processor. Such measurements will be invalid if the lubricant alters the intracochlear electrical impedance such that the compliance voltage of the stimulator is reached, or if the current is directed away from the neural structures.

In this study, the impedances of hyaluronic acid, oxycellulose, and glycerin, both in pure form as well

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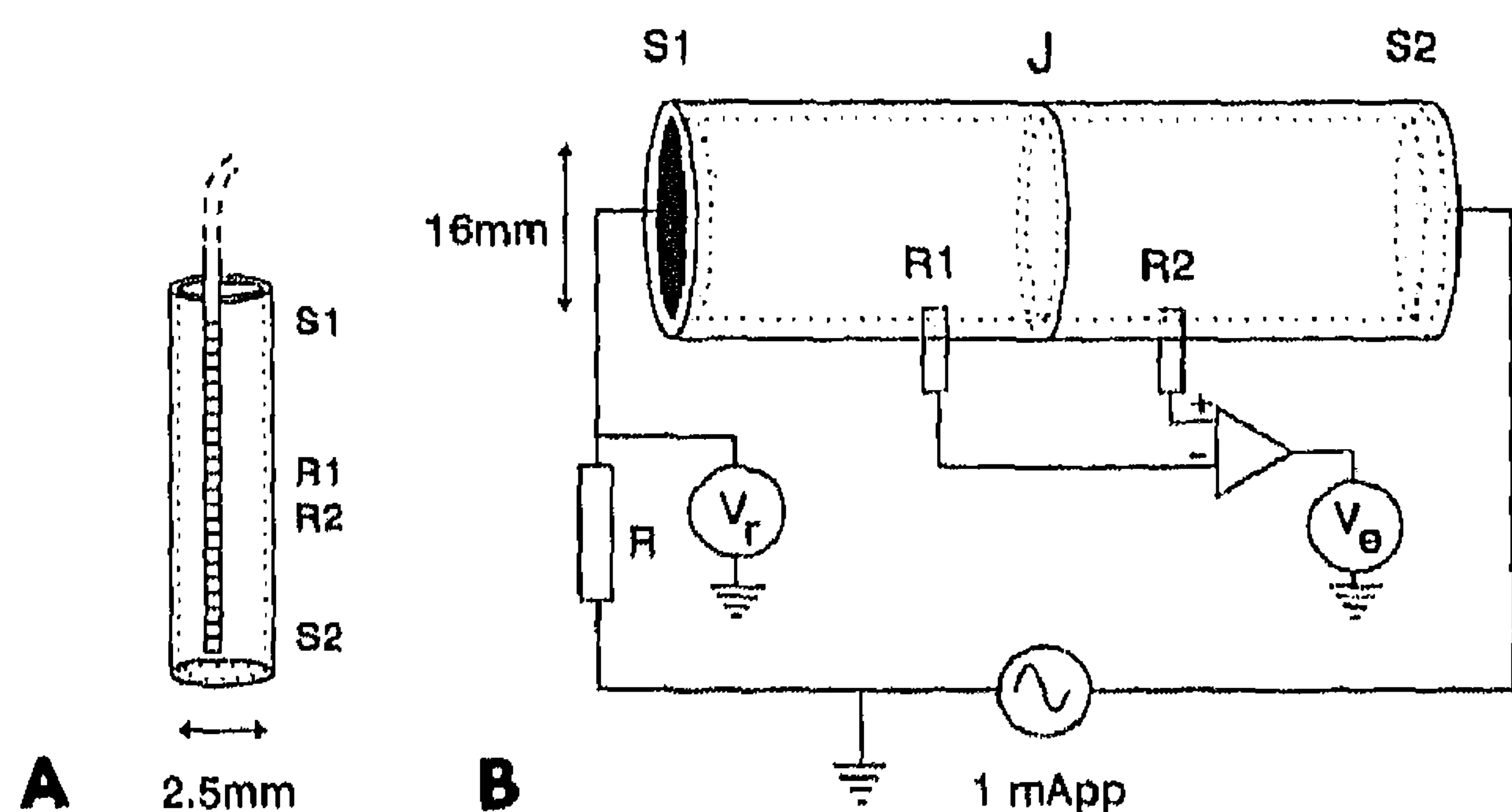


Fig 1. Test containers used for resistivity measurements. A) Test container A, small tube; Nucleus array was free-fitted. S1 and S2 are stimulated electrodes; R1 and R2 are electrodes used for registration. B) Test container B, Perspex cylinder in which specimen could be fitted at J. Illustrates four-terminal method. See text for abbreviations.

as in thin films, were compared to the impedance of saline.

METHODS

The 22 electrodes of the Nucleus Mini System 22 are bands (rings) of pure platinum, 0.3 mm wide and spaced at 0.75-mm intervals along the distal 17 mm of a silicone elastomer carrier. The electrode array tapers smoothly from a diameter of 0.6 mm at its widest part, where it enters the round window when implanted, to about 0.4 mm at the tip. The electrodes are numbered 1 to 22 from base to tip.

The impedance was measured by the four-terminal method,⁷ which eliminates electrode polarization as a contaminating factor. Two test containers were used (Fig 1).

Container A was a small cylindrical tube (radius 1.25 mm); an experimental version of the Nucleus Mini System 22 electrode array was fitted along its central axis. This device provided direct electrical access to the electrodes. The two outermost electrodes (Nos. 1 and 22; S1 and S2 in Fig 1A) were used to apply an excitation current. The potential difference between the two inner electrodes (Nos. 10 and 14; R1 and R2 in Fig 1A) was measured. Container B consisted of a Perspex cylinder (radius 8 mm) closed at both ends by silver chloride electrodes (S1 and S2), to which the current could be applied. Two small sensing electrodes (R1 and R2) were fitted into the wall of the container 12 mm from a central junction (J in Fig 1B). A specimen of material could be mounted at the junction.

In each container, the two outermost electrodes were used to induce a current of 1 mA (peak to peak) as established by measuring the potential difference V_r across a resistance R of 1 kilo-ohm ($k\Omega$; Fig 1B). The potential difference V_e across the sensing elec-

trodes was measured to yield the impedance Z. The resistivity ρ of the section of the container between the two inner electrodes was derived from

$$\rho = Z \times \frac{O}{d}$$

where O is the cross section of the container (minus that of the electrode array in the case of container A) and d is the distance between the sensing electrodes. The impedances were measured with a sinusoidal driving voltage in the frequency range from 20 Hz to 1 MHz. Phase differences were measured by displaying V_r and V_e simultaneously on an oscilloscope with a differential channel used for V_e . In addition to the resistivity measurements, the impedance between stimulated electrodes was derived with a sinusoidal driving current of 1 mA (peak to peak).

Measurements were taken in container A with a Nucleus Mini System 22 electrode array 1) immersed in undiluted lubricant and 2) covered with a film of lubricant immersed in saline (mimicking the surgical procedure) to study interfacial polarization. Interfacial polarization effects were also assessed by measuring across a piece of tissue paper soaked with the lubricant fitted at the central junction of container B.

The electrodes of the implant array that were not involved in the measurement were disconnected. However, the total area of the banded electrodes is considerable and may present a low-impedance path in container A. Control measurements in saline were therefore taken in container B.

Far-field current spread was measured by immersing the array into a shallow water tank filled with saline solution. The electrode array was positioned parallel to the line between the sensing electrodes; the array was positioned at one end of the tank, 12 cm away from the sensing electrodes at the other end. The sensing electrodes were 4 cm apart.

The hyaluronic acid was 10 mg/mL sodium hyaluronate (Healon) from Kabi Pharmacia. Oxycellulose was prepared as 1% hypromellose with 9 mg/mL sodium chloride and 0.5 mg/mL borax. Glycerin was 85% glycerol and 15% water with less than 0.001% residual elements. Saline was sodium chloride 0.9 g/L. Measurements were taken at 22°C and 37°C ($\pm 2^\circ\text{C}$).

RESULTS

The four-terminal method requires a homogeneous sample. Although the array was free-fitted in container A, with considerable deviations from the central axis, a uniform voltage drop was present in saline across all the electrodes 2 through 21, with a constant current between electrodes 1 and 22. This suggests

RESISTIVITY AT 10 KILOHERTZ

Temperature	Saline 0.9 g/L	Undiluted Hyaluronic Acid	Undiluted Glycerin	Undiluted Oxycellulose
22°C	59 ± 9	61 ± 9	(34 ± 5) × 10 ³	60 ± 9
37°C	44 ± 7	44 ± 7	(49 ± 7) × 10 ³	46 ± 7

Data are in Ω·cm, and represent value ± error margin based on estimated accuracy with which voltage and current readings were obtained.

that the requirement of homogeneity was satisfied. The large platinum-banded electrodes did have some effect on the resistivities measured. A resistivity of 59 Ω·cm was measured in saline at 22°C at a frequency of 1 kHz when the implant was inserted into container A, compared to 64 Ω·cm for saline measured in container B. Weast et al⁸ give a value of 61.1 Ω·cm for the resistivity of saline at 22°C. These deviations were considered to be minor, and no correction was applied to the data obtained from container A.

The Table lists the resistivity values at 10 kHz for the undiluted lubricants and saline in container A.

In Fig 2, the resistivities of saline, hyaluronic acid, and oxycellulose are displayed as a function of frequency. This Figure shows that the resistivities were largely independent of the frequency up to about 500 kHz. Glycerin displayed a high-pass character across the frequency range applied in this study.

In repeated tests, the resistivity of glycerin was found to increase by about 1.5%/°C at 10 kHz, in contrast with a negative temperature coefficient for the other materials.

The application of a thin film of hyaluronic acid or oxycellulose around the electrode array immersed in saline (37°C) did not have any measurable effect on the impedance. A film of glycerin, however, resulted in an "effective resistivity" of 149, 80, and 58 Ω·cm at 1, 10, and 100 kHz (compared to the 44 Ω·cm for saline) and a phase angle of 180° at all the frequencies, which suggested interfacial polarization. Therefore, the volume conduction in container A with a film of glycerin was not homogeneous, and the resistivity could not be measured.

No fluid-fluid boundary effects were found for hyaluronic acid or oxycellulose when they were applied to a piece of tissue paper separating the two halves of container B. The application of glycerin, on the other hand, increased the magnitude of the impedance by about 30% at 1 kHz, by 15% at 10 kHz, and by 10% at 100 kHz.

The impedance between the stimulated electrodes

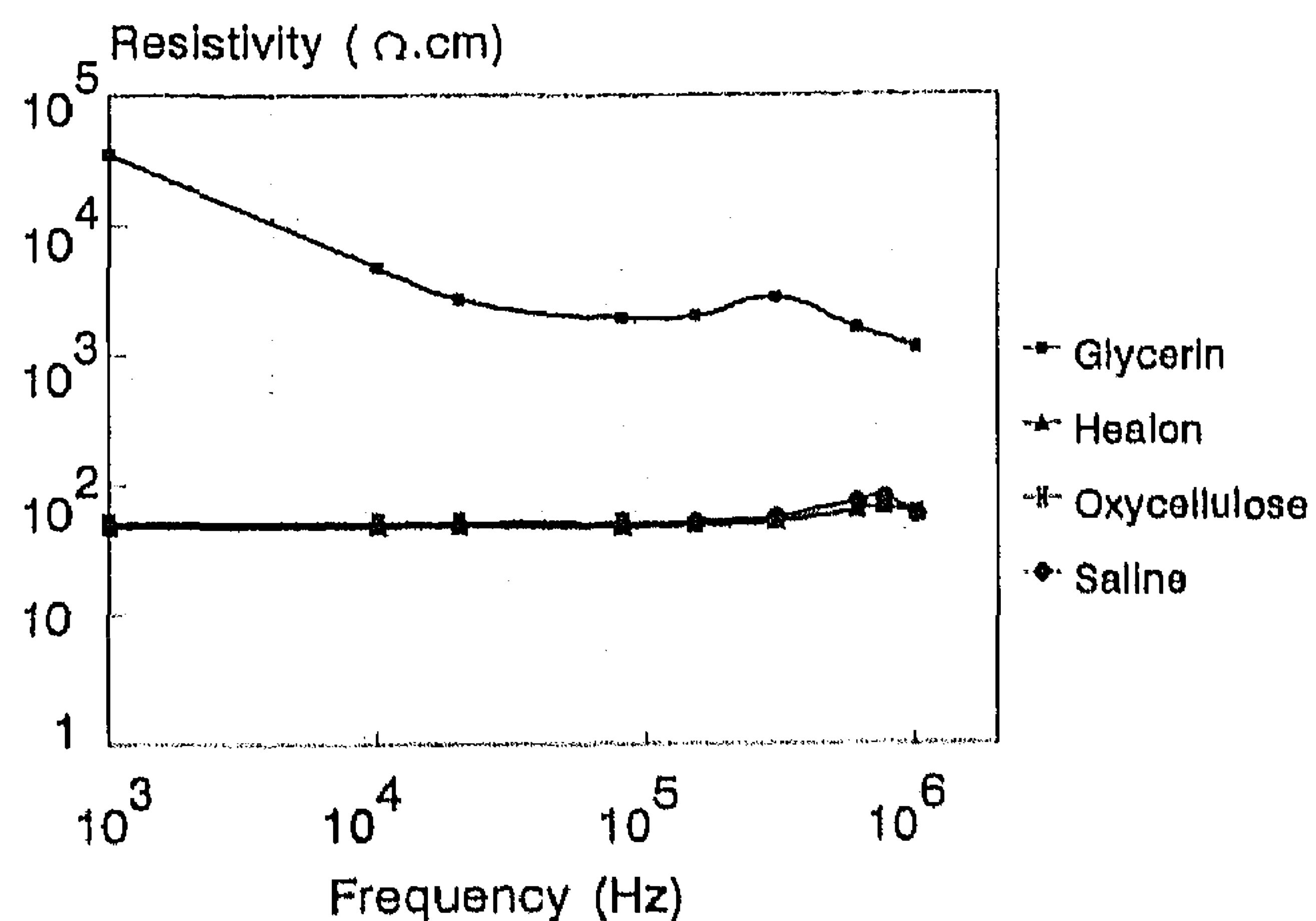


Fig 2. Resistivity as function of frequency at 22°C of impressed sinusoidal current.

of the Nucleus array in container A when it was filled with saline, undiluted hyaluronic acid, or undiluted oxycellulose was a modest 2.5 kΩ at 37°C and 10 kHz and almost completely resistive. Undiluted glycerin displayed a high-pass character with an impedance of 510 kΩ at 10 kHz that dropped to 266 kΩ at 100 kHz. A film of glycerin applied to the electrode array did not affect the impedance across the stimulated electrodes.

The interfacial polarization caused by a film of glycerin did not significantly affect the far-field current spread measured in a tank filled with saline, not even when the common ground stimulation mode was used.

DISCUSSION

In the undiluted form, glycerin was the only lubricant in which the impedance deviated significantly from that of saline. In the frequency range relevant for stimulation of the cochlear nerve, undiluted glycerin displayed a high-pass character. When immersed in undiluted glycerin, the maximum current level for the Nucleus implanted current source would be about 40 μA at 10 kHz, instead of the design specification of 1,500 μA (given the maximum compliance voltage of 20 V peak to peak).

The substances were also applied as a thin film. Only glycerin had an effect on the impedance, including a 180° phase shift. However, a film of glycerin did not affect the impedance between the stimulated electrodes or the far-field current spread measured with distant sensing electrodes. We conclude that a film of glycerin around the electrode array resulted in a polarization layer affecting the current flow along the surface of the electrode array without a substantial effect on the overall volume conduction for the driving current. Far-field effects were not observed even in the common ground stimulation mode, in

which the spatial current distribution is most likely to be affected by impedance shifts.⁹

In sum, none of these lubricants are expected to

alter the current flow toward the excitable elements. They do not seem to affect intraoperative electrically elicited stapedius reflex or auditory brain stem response measurements.

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