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A DIGITAL COMPUTER MODEL OF ELECTRICAL STIMULATION IN THE HUMAN COCHLEA FOR AUDITORY PROSTHESIS RESEARCH

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SUMMARY

A three-dimensional model of electrical stimulation in the human cochlea has been developed and implemented on a digital computer. The model was used to estimate the distributions of electric potential and current density in the human cochlea in response to electrical stimulation using scala tympani electrodes. The computed distributions were used to investigate the relative merits of two scala tympani electrode designs. The results showed that the electrode design consisting of a medial electrode pair in the scala tympani is a more viable alternative than a lateral electrode pair for patients suffering from profound-to-total hearing impairment.

INTRODUCTION

To present useful multi-component auditory information to profoundly-to-totally deaf patients who are implanted with a cochlear implant auditory prosthesis [1], it is important to investigate the distribution of electric potential and current density in the human cochlea in response to electrical stimulation using scala tympani electrodes. This paper describes a digital computer model of electrical stimulation estimating these distributions in the human cochlea. The computed distributions obtained from this model were used to investigate the relative merits of two scala tympani electrode designs for a cochlear implant prosthesis.

DESCRIPTION OF THE MODEL

The three-dimensional model encompasses the cochlea, the auditory nerve trunk in the internal auditory meatus, the surrounding temporal bone, and the implanted scala tympani electrode array. The three-dimensional model is made up of contiguous hexahedral elements of the same size. Each element represents cochlear fluid, soft tissue, bone, neural tissue or electrode material. The physical arrangement of the elements is derived from serial sections (100 microns apart) of human temporal bones. For each serial section, the boundaries of different anatomical and electrode regions were traced using an image analyzer. The model assumes that impedances are purely resistive. For each section, resistivities are assigned to different regions (groups of elements of the same material) according to published resistivity data. The quasi-static Maxwell's equations describing the relationship between the electric potential distribution of the model and the volume current source density at the electrode surface are numerically simulated by the finite difference method on a Cyber 990 digital computer. We have to-date successfully calculated the electric potential distribution of a simplified three-dimensional model of 2,682,240 elements. In this simplified model, a two-dimensional mid-modiolar section of a temporal bone was digitized into a x-y grid of 254x244 elements. A three-dimensional model was constructed by arranging thirty copies of this digitized section in parallel along an axis perpendicular to the plane of the section. This axis will be called the z-axis in this paper. A layer of insulator, five elements thick, was included on the outside of each side of the model. There were therefore a total of 264x254x40=2,682,240 elements in the model. The dimensions of each element in cm were 0.002(x), 0.0015(y), and 0.01(z). Simulated electrical stimulation was provided by two point sources arranged as a bipolar pair in the scala tympani along a line parallel to the z-axis. Fig. 1 shows a schematic diagram of this model. The two point sources were in sections 13 and 28, respectively, and were therefore 1.5 mm apart. The electric potential distributions for two locations of scala tympani electrodes were computed. At the medial location, the two point sources were closer to the spiral ganglions; at the lateral location, the two point sources were closer to the organ of Corti. The resistivities assigned to the different materials in the model are tabulated in Table 1. The electric currents applied to the two point sources of each location were plus and minus 0.4 mA, respectively.

RESULTS AND DISCUSSION

In order to compare the relative merits of the two electrode locations (medial and lateral), the potential distributions in the vicinity of the neural elements of the cochlea were examined. It is important to study these distributions because they determine the neural excitation pattern in the auditory nerve of cochlear implant patients. To facilitate these examinations, a neural surface was defined in the model. The neural surface consists of the 30 neural paths in the 30 z-sections corresponding to the cochlear canals of the model; note that no neural or biological materials are present in the remaining ten sections of insulating materials. The neural path which is identical in each section is schematically shown in Fig. 2. There are 125 model elements in the neural path. The neural path consists of the following four sections : (a) the peripheral process in the spiral lamina (elements 1-59); (b) the vertical segment of the peripheral process in the modiolas (60-89); (c) lateral part of the spiral ganglion (90-107); and (d) medial part of the spiral ganglion (108-125).

Fig. 2 shows the potential distribution along the neural path for z-section number 13 where one of the two point sources of the bipolar electrode pair was located. Two curves are shown. The solid curve corresponds to the potential distribution for the medially located electrode pair, while the dashed curve shows the distribution for the laterally located electrode pair. Element numbers along the neural path are shown on the abscissa.

From Fig. 2, it can be seen that, with the exception of a small region at the organ of Corti end (element number 1) of the neural path, the absolute value of the potential is greater for the medial electrodes than for the lateral electrodes. The potential difference between the two ends of the spiral lamina is similar for the two electrode locations. This implies that for patients with good survival of the peripheral process in the spiral lamina, the two electrode locations are equally effective in initiating neural discharge at this site. The potential difference over the spiral ganglion, on the other hand, is greater for the medial electrodes than for the lateral electrodes. This implies that the medial electrodes are more effective for neural excitation at the spiral ganglion. Since histopathological studies [2] have shown that, for a majority of cochlear implant candidates, survival of the peripheral process is poor. It therefore appears that the medial electrode position is a more viable alternative for restoring useful hearing in profound-to-total hearing impairment.

REFERENCES

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TABLE 1 : Resistivities used in the models (ohm.cm)

bone	1600
connective tissue	160
platinum	1
neural tissue	500
perilymph and endolymph	65.5
insulator	20,000

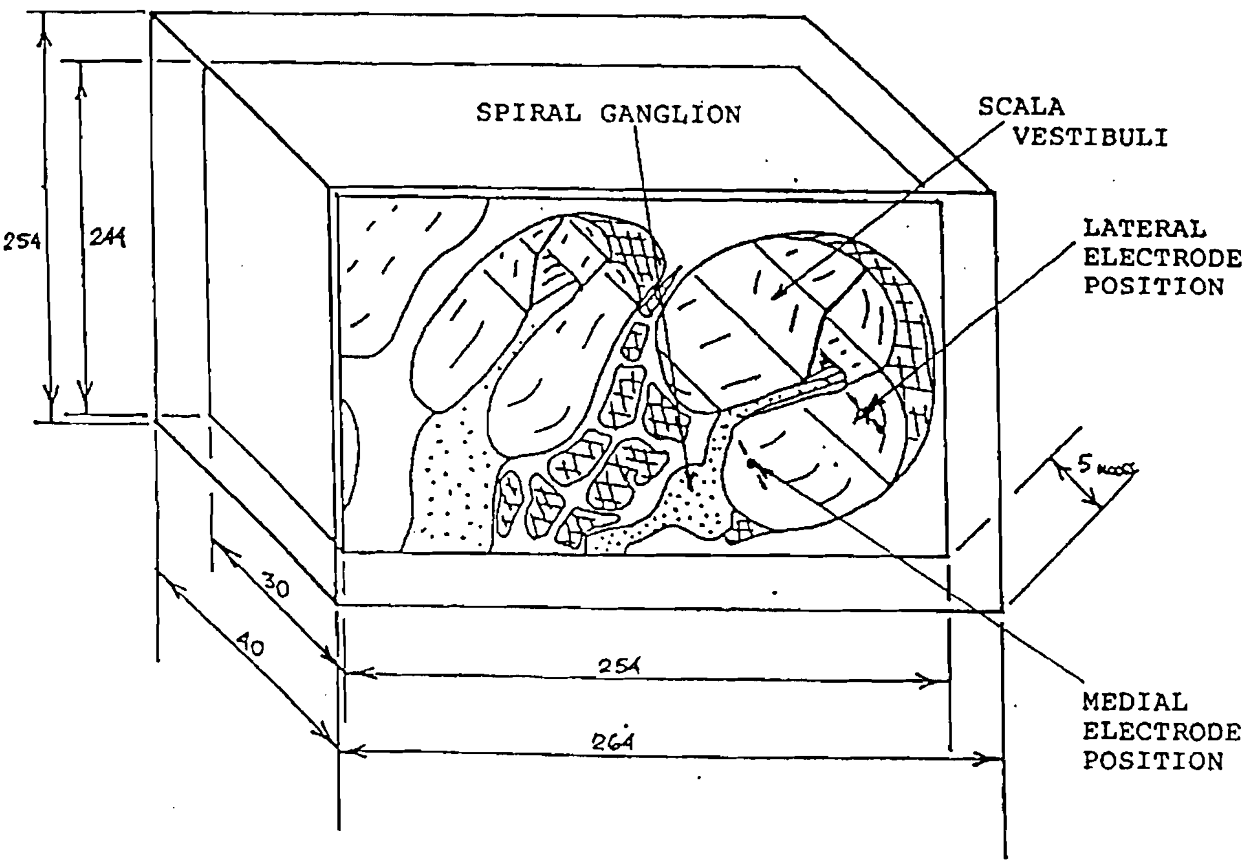

FIG 1 : SCHEMATIC DIAGRAM OF THE THREE DIMENSIONAL MODEL

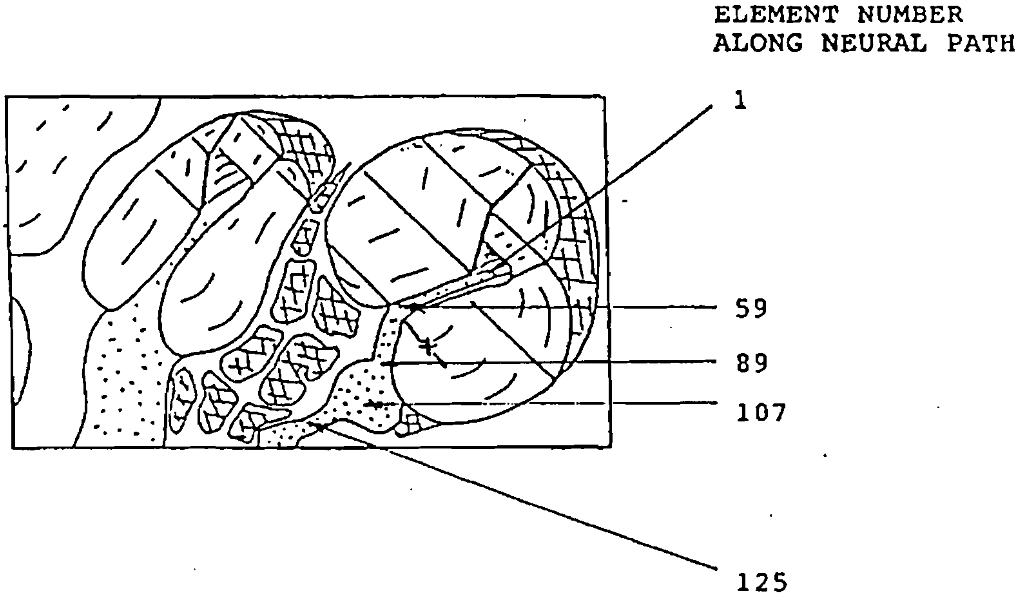

FIG 2 : NEURAL PATH OF 125 ELEMENTS

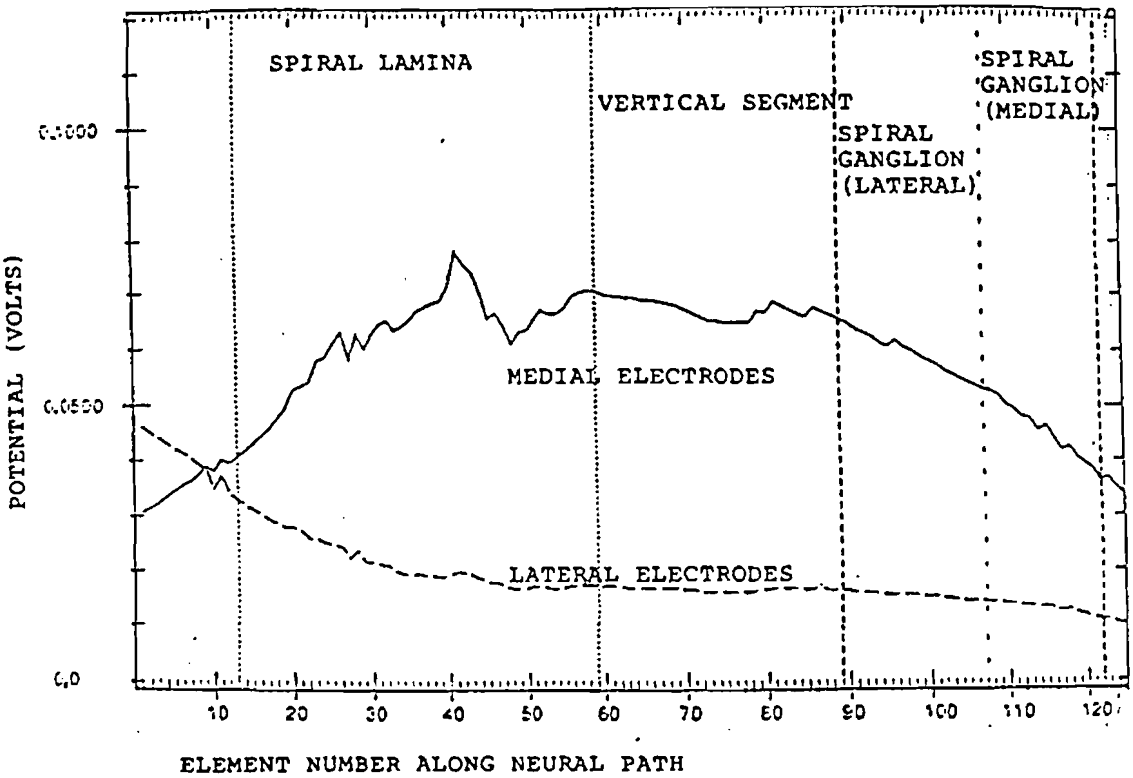

FIG 3 : POTENTIAL DISTRIBUTIONS ALONG THE NEURAL PATH FOR TWO ELECTRODE POSITIONS

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