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(*Founded in* 1887 *by* MORELL MACKENZIE *and* NORRIS WOLFENDEN)

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A cochlear implant electrode

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Introduction

IF patients with severe sensorineural deafness are going to perceive speech by electrical stimulation of the terminal auditory nerve fibres, it must be carried out on the basis of the place theory of pitch perception, as experimental studies have shown that electrical stimulation with single electrodes on the basis of the volley theory is not satisfactory (Clark, 1969; Kiang and Moxon, 1972; Simmons and Glattke, 1972). For this reason, it will be necessary to develop an array of electrodes that will enable a number of different auditory nerve fibres to be stimulated separately.

Electrical stimulation at precise locations in the auditory nerve is more likely to be achieved with an electrode array inserted along the length of the scala tympani of the cochlea rather than directly into the auditory nerve. However, a clinical report by Michelson (1971) indicates that it is difficult to do this, as he was not able to introduce an array further than the basal turn.

For this reason we have carried out a series of experimental studies to help determine the mechanical properties of the electrode array and the method of insertion that will enable it to be inserted the whole length of the cochlea, and so permit a number of different nerve fibres to be stimulated.

Methods

The medial wall of the middle ear in three fresh human temporal bones was exposed. The scala tympani of the middle and apical turns were opened by drilling through the overlying bone at points which were 2·5 mm. and 4·0 mm. respectively anterior to the centre of the oval window, and along a line at right angles to a line drawn between the centres of the oval and round windows (Clark, in press). An opening was also made in the basal turn anteroinferior to the round window. Electrodes with different mechanical properties were then inserted into the basal turn through the round window membrane, and directly into the middle and apical turns. The electrode inserted into the middle turn was passed in both an apical and basal direction, while the electrode in the apical turn was passed in a basal direction. This is illustrated in Figure 1, which shows a diagram of the cochlea with an electrode inserted through an opening in the apical turn into the middle and basal turns. The distance the electrode could be passed was measured in each case.

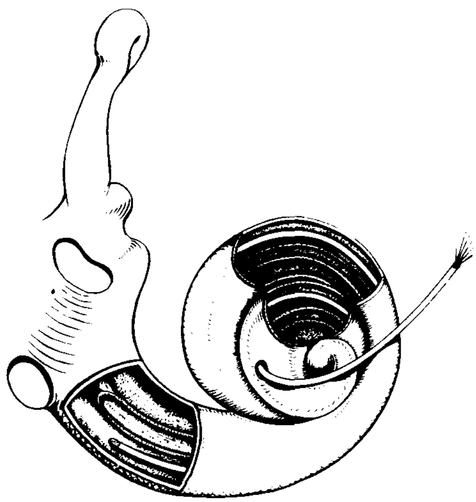

FIG. 1.
A diagram of the cochlea with an electrode inserted through an opening in the apical turn into the middle and basal turns.

A similar study has also been carried out on a model of the human cochlea. This model was made by soaking the temporal bones in trypsin and boiling them to remove the soft tissue. They were then dried, and the bony labyrinth filled with wax. The surrounding bone was removed with concentrated hydrochloric acid leaving the positive cast of the labyrinth. This was then coated with an expoxylite resin. Relieving holes were made in the resin and the wax removed by a combination of heating and soaking in xylene to produce a negative cast of the cochlea. An opening into the cast was made through the round window and overlying the apical turn. The electrodes were introduced through these apertures, and their progress around the coils could be observed through the operating microscope as the resin was relatively transparent, particularly when immersed in xylene. This can be seen in Figure 2, which is a photograph of the cast showing the electrode inserted through an opening in the apical turn into the middle and basal turns.

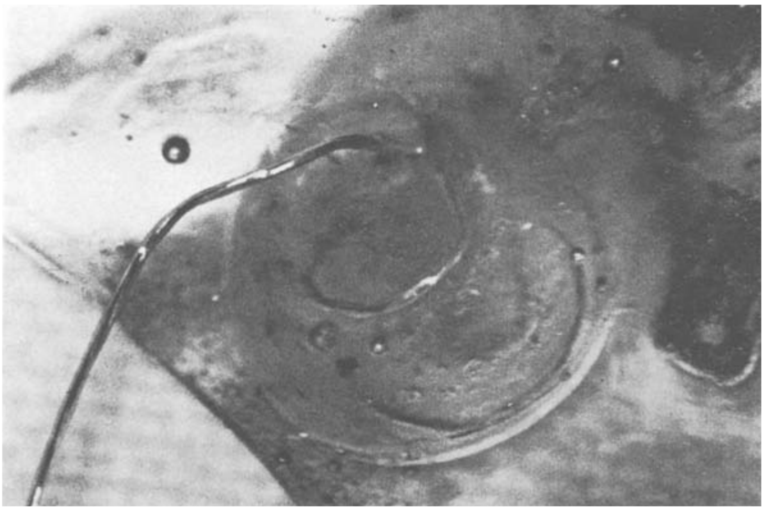

FIG. 2.
A photograph of a cast of the cochlea showing an electrode inserted through an opening in the apical turn into the middle and basal turns. ×16.

The main parameters of the electrode array that were measured were stiffness and extensibility. The stiffness of an electrode is the load required to produce a given extension per unit length in that electrode. The total extension can then be obtained when the length of electrode inserted into the cochlea is known. Stiffness has the units of force, and is a function of the electrode's cross-sectional area and the materials of which it is made. For a reasonable amount of extension, the stiffness of our electrodes was constant, and its optimum value was 2·4 N. The extensibility is best assessed by the per unit length extension of the electrode at its break load. This was found to be 7 per cent or greater. In comparison the maximum expected per unit length extension, based on cochlear geometry, is 5 per cent.

Results

The results of this study to introduce electrode arrays into the basal, middle and apical turns of the human cochlea showed that, when electrodes were inserted into the basal and middle turns and advanced in an apical direction, they soon met considerable resistance, and could not be inserted more than 10 mm. On the other hand, when the electrode array was inserted into the apical turn, and advanced in a basal direction, it could be passed along almost the whole length of the cochlea. This is shown in

Figure 3, which is a photograph of the medial wall of the temporal bone with the electrode entering the cochlea through an opening in the apical turn, and passing around the middle to the basal turn.

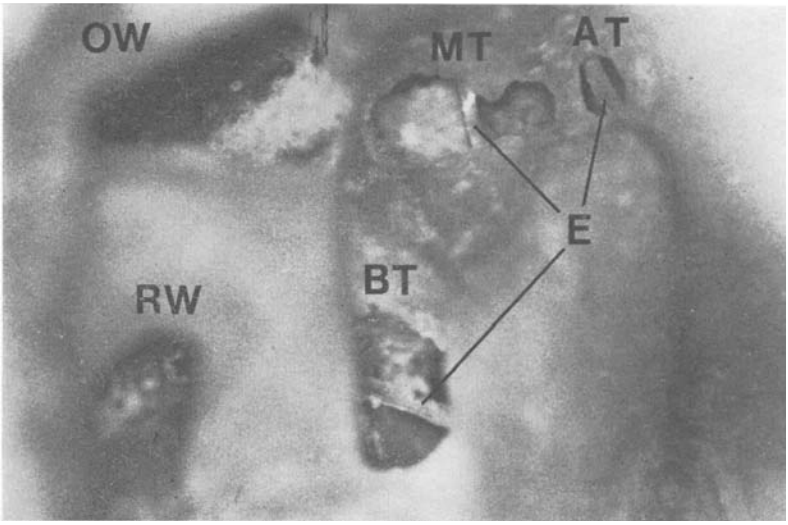

FIG. 3.
A photograph of the medial wall of a temporal bone with the electrode entering the cochlea through an opening in the apical turn and passing around the middle to the basal turn. ×16.

OW — oval window; RW — round window;
BT — basal turn; MT — middle turn;
AT — apical turn; E — electrode.

In a similar set of experiments on a model of the cochlea, it was also shown that the electrode array could not be inserted through the round window into the basal turn more than 10 mm. On the other hand, when inserted into the apical turn, it passed relatively easily into the basal turn. The passage of this electrode around the coils of the cochlea could be observed, and it was noted that the electrode impinged on the lateral wall of the cochlea at a number of points. If the electrode array was sufficiently stiff to transmit a force to this area and overcome the resistance, it continued its passage towards the basal turn.

When passing an electrode around the coils of the cochlea, it was noted that if the electrode was too stiff the end could impinge on the outer wall and this would impede its progress. On the other hand, if it was too flexible, it would tend to coil on itself and this would impede its progress. Consequently, the electrode needed to have an optimum degree of stiffness before it would pass satisfactorily, and this was 2·4 N.

Discussion

From this study, it can be seen that it was much easier to pass a wire around a coil when the spiral was expanding rather than tightening, and it was also shown that it was possible to pass an electrode array nearly the whole length of the cochlea by inserting it through a small opening overlying the apical turn.

In making this opening the overlying bone is drilled away with a 1 mm. diamond paste burr to a depth of 1 mm. under a magnification of ×16. This cavity is drilled at a point which is 4 mm. anterior to the centre of the oval window and slightly below a line at right angles to a line between the centres of the oval and round windows (Clark, in press). Further drilling is continued with suction-irrigation using a 0·6 mm. diamond paste burr under a magnification of ×25. At a depth of about 1·5 mm. a blue line is seen, which is produced by the underlying stria vascularis. Further drilling is continued under a magnification of ×40 slightly posterior to this line until the endosteal lining of the scala tympani is exposed. A small dissector is used to strip this upwards, and an opening is made with a needle to allow the electrode array to be passed into the scala tympani. This operative approach is illustrated in the diagram in Figure 4.

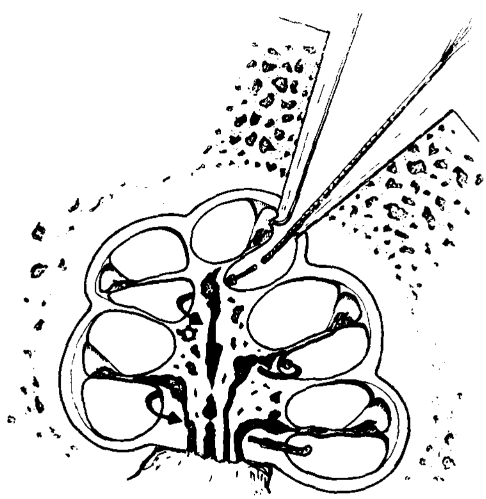

FIG. 4.

A diagram of a cross-section of the cochlea showing the operative approach to the scala tympani of the apical turn.

A previous study (Clark *et al.*, in press) has shown that it is possible to insert an electrode into the apical turn of the cochlea without producing a significant loss in spiral ganglion cells and auditory nerve fibres, provided infection does not occur. Consequently, this electrode and operative approach could be used in stimulating the terminal auditory nerve fibres on a place basis, and so help patients with severe sensorineural deafness.

Summary

This study has shown that an electrode array can be passed along the whole length of the cochlea if it is inserted through an opening in the scala tympani of the apical turn. The electrode must have the appropriate mechanical properties and some of these were stiffness and extensibility. This electrode and operative approach should be helpful in stimulating the terminal auditory nerve fibres on a place basis, which is desirable if patients with severe sensorineural deafness are to be helped with a cochlear implant.

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