THE HUMAN COCHLEA DURING DEVELOPMENT AND AGEING*

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SINCE its discovery over a century ago the organ of Corti has been subject to research from a functional as well as from a clinical point of view.

Clinical audiology has advanced far in an attempt to correlate hearing with labyrinthine disorders but the morphological basis for this has not been exploited to that extent and remains but poorly understood. This is not due to a lack of interest shown in this field but the laborious methods applied have been mainly responsible for the little knowledge, at times erroneous, we have acquired on the subject. Corresponding pathological changes have been studied in cochleas obtained from animals of different species exposed to the damaging effects of noise. No comprehensive investigation to date has been made to study the morphological changes occurring in the cochlea of man and to correlate these with hearing at different ages.

In the light of past experience and in the knowledge of the limits of basic histological techniques in the morphological study of the labyrinth, the surface specimen technique was reviewed, improved and applied by Engström. It has brought to us a new dimensional view in our studies and the technique constitutes a significant step in the improvement of our methods. With these facilities at hand and because of an interest aroused in associating hearing with morphological changes observed in the human cochlea this study began, Bredberg *et al.* (1965).

The method used in the study of the human cochlea is the technique of serial sectioning. When used exclusively, this method has certain disadvantages and some are worthy of mention here. The time factor is important, for this method entails procedures of decalcification and embedding which take several months. The embedded temporal bone is sectioned and every tenth section is then examined so as to allow of reconstruction later. The sections may in themselves be non-representative of the field under study and important observations made on the relationship of the different sensory and supporting cells may be missed. It may be added that there is a relatively high incidence of artefacts difficult at times to differentiate from pathological conditions.

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Retzius, in 1884, published an excellent description of the cyto-architecture of the organ of Corti of man. The association of hearing loss to cochlear pathology was first studied to any extent by Crowe, Guild and Polvogt, in 1934, in their classical paper on high tone deafness. They studied a total of seventy-nine ears obtained from subjects who during life have had their hearing assessed by means of pure tone audiometry. Another classical paper in this field is that of the study on presbyacusis by v. Fieandt and Saxén in 1937. Schuknecht *et al.* (1962 a, b, 1964 a, b) has during the last decade published several papers on cochlear pathology as compared with hearing. There have been several other works in the same field but the above mentioned are the most exhaustive.

The ultrastructure of the organ of Corti in man was recently studied by Kimura *et al.* (1964).

Its development in animals has been studied by several authors but relatively few have made corresponding studies on the development of the human cochlea (Streeter, 1918; Kolmer 1927; Bast and Anson, 1949; Altmann, 1950).

Material

The material used in this study consists of 150 cochleas obtained at autopsy from human foetuses, infants, children and adults of various ages and of both sexes. Fifteen subjects, prior to death, have had their hearing audiologically tested. Naturally it was impossible to assess the hearing in all cases particularly of those in the younger age groups. This has restricted the number of cases whose hearing was to be correlated with morphological findings.

Methods

To ensure early fixation and thus reduce the degree of post mortem autolysis the following method has been used. As soon as possible after death the posterior half of the tympanic membrane was reflected forward via an endaural approach to the middle ear cavity. Access to the labyrinth was obtained by removal of the footplate of the stapes and the round window membrane. A 1½ per cent. veronal buffered osmic acid solution was slowly injected through the round window. The cochlea thus perfused was sealed off by paraffin which was placed in the external auditory canal. The fixative thus remained in situ until such time as autopsy could be performed and the temporal bone removed. By means of dental diamond burrs the cochlea was then drilled free and thus removed from the surrounding bone.

With care the bony shell of the labyrinth was removed thus exposing and laying free the membranous cochlea. The spiral ligament and the stria vascularis were then stripped off all coils. The specimen now allows

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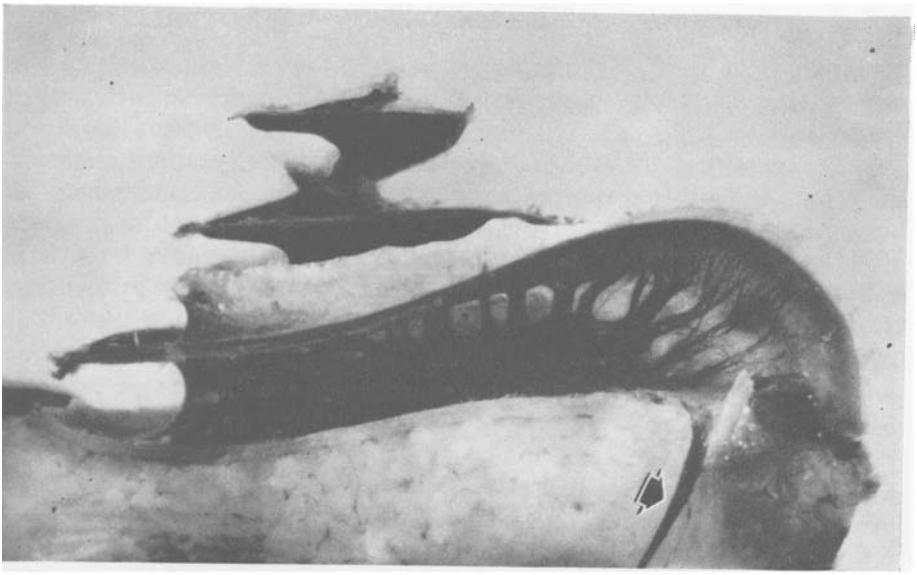


FIG. 1

Adult human cochlea showing the modiolus with the spiral osseous lamina and associated nerve bundles. The cochlear aqueduct (arrow) is shown lying opened and continuous with scala tympani. (Fixative: osmic acid solution.) (Magnification ×12.)

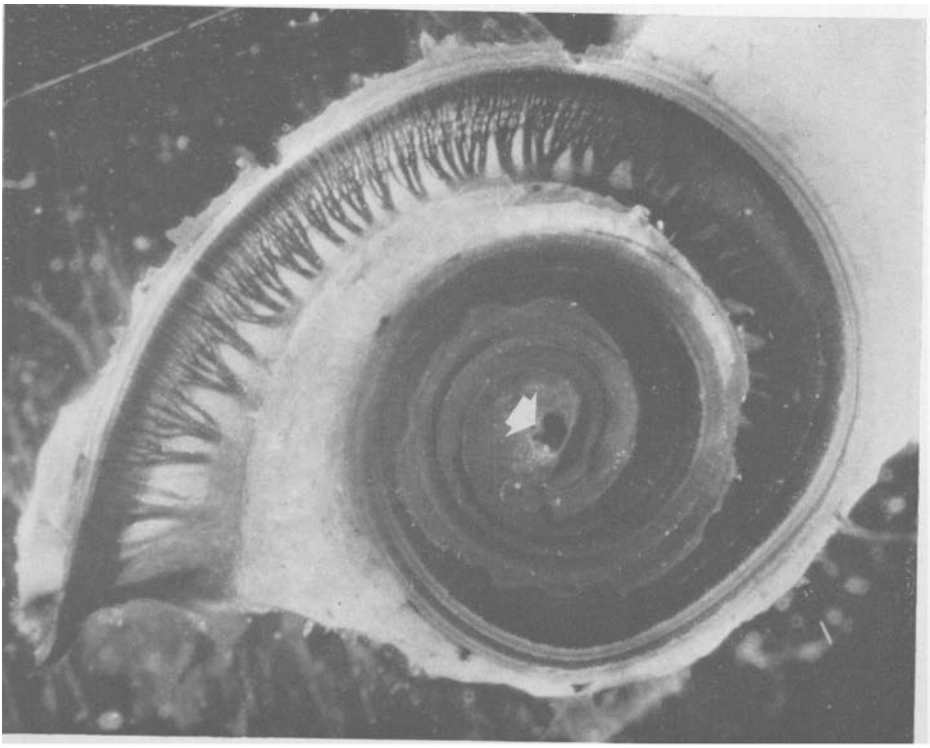


FIG. 2

Human cochlea, as seen from above. Myelinated nerve bundles within the spiral osseous lamina show well in the lower basal coil. Note helicotrema at the apex (arrow). The organ of Corti is seen lying at the peripheral margin of the spiral osseous lamina. (Magnification ×13.)

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of an excellent view of the organ of Corti throughout the whole of the cochlea, the spiral osseous lamina and associated nerves as well as the modiolus (Figs. 1, 2, 3).

The cellular pattern of the organ of Corti, segmentally or in its entirety or in fact any other structure within the membranous cochlea may be chosen for examination under high magnification in the light microscope.

The preparation of such a specimen and the examination of its surface as well as of regions at different levels within the organ of Corti by focusing at different optical planes under the light microscope constitute the essentials of the "surface specimen technique" (Engström *et al.* 1966).

Results

In a *two and a half month* human embryo it is difficult to differentiate supporting cells from sensory cells in the organ of Corti. Thereafter and for the following four months development is rapid. This commences in the basal coil and advances gradually in an apical direction.

At *three months* the outer hair cells in the lower basal coil are disposed in three regular rows and have a round free upper surface, whereas the inner hair cells lie in a single row and present a larger free upper surface, indicating that inner sensory cells develop earlier than the outer

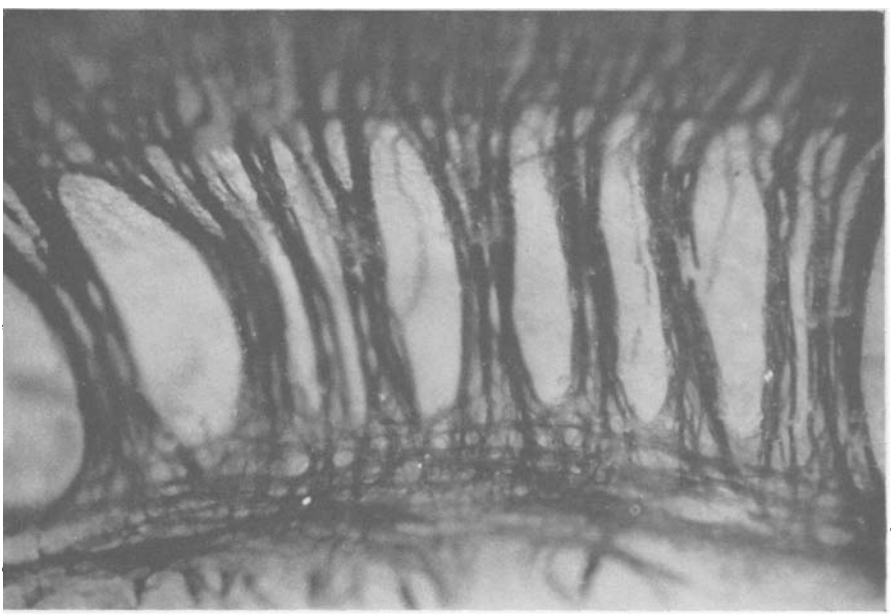


FIG. 3

Segment of the basal coil as seen from below showing nerve bundles reaching the organ of Corti above. Efferent fibres forming Rasmussen's bundle are seen to be running transversely within the modiolus below. (Magnification ×48.)

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(Figs. 4, 5). In the second coil the outer hair cells though similarly arranged have an almost square but smaller free surface. In the apical coil both inner and outer hair cells are smaller than those in the lower coils. The arrangement of sensory cells in the outer rows is irregular. There is a close resemblance between supporting elements and sensory cells, but the surface of the latter appear darker in the osmium fixed specimen (Fig. 5). This may well be due to an early differentiation at the cell surface of a cuticle and its associated hairs. Throughout the whole extent of the cochlea the inner and outer hair cells are separated by the inner and outer pillar cells; at the free surface, however, the inner pillar heads alone are represented (Fig. 4).

At *four months* the sensory cells throughout the cochlea are disposed in three or four regularly arranged rows and the cell surface has an almost adult size. The stereccilia on the free cell surface are now apparent and

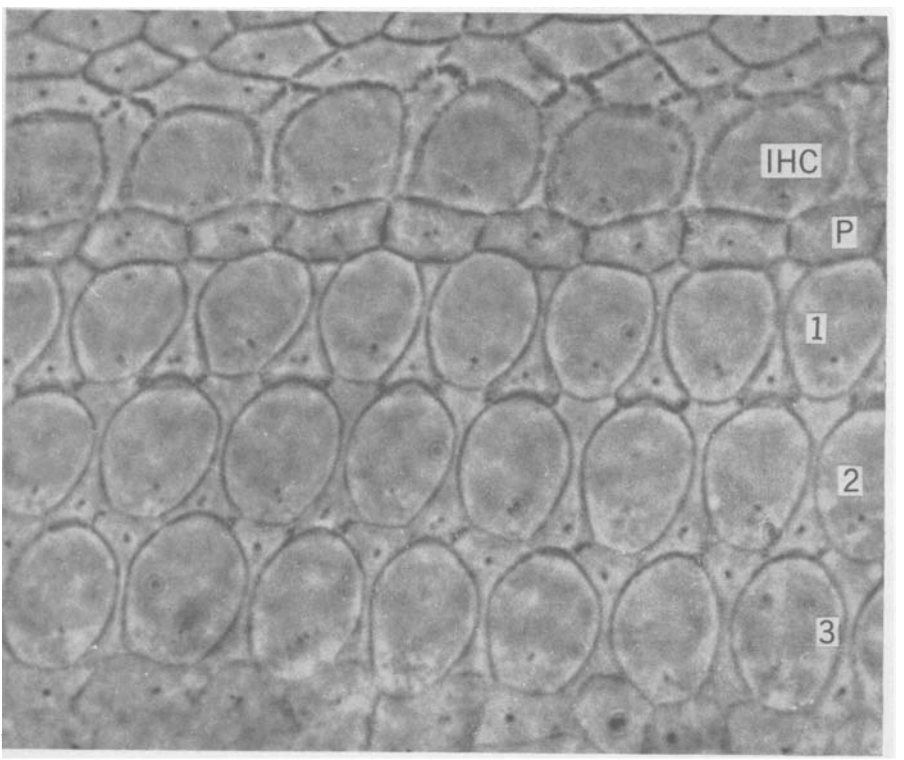


FIG. 4

Organ of Corti (human foetus, 15 wks.) surface specimen from lower basal coil showing three rows of outer hair cells (1, 2, 3) separated from a row of inner hair cells (I.H.C.) by the inner pillar heads (P.). Note the regular arrangement of the cells. Black dots seen on both sensory and supporting cells represent modified kinocilia. (Magnification × 1,560.)

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display the normal characteristic W-shaped pattern. A single modified kinociium is present on each sensory and supporting cell and its basal body is conspicuous as a black dot in osmic acid fixed specimens.

At *five to six months* there is a loss in the uniform regularity of the cellular pattern; in some parts the pattern of the outer hair cells is quite regular (Fig. 6) whilst in others it may appear irregular (Fig. 7). Again whilst such irregularities are known to occur in man the cellular pattern in other mammals, however, remains constant (bat, rat, guinea pig, rabbit, cat). At this age the outer hair cells are often disposed in four or five rows in the more apical coils.

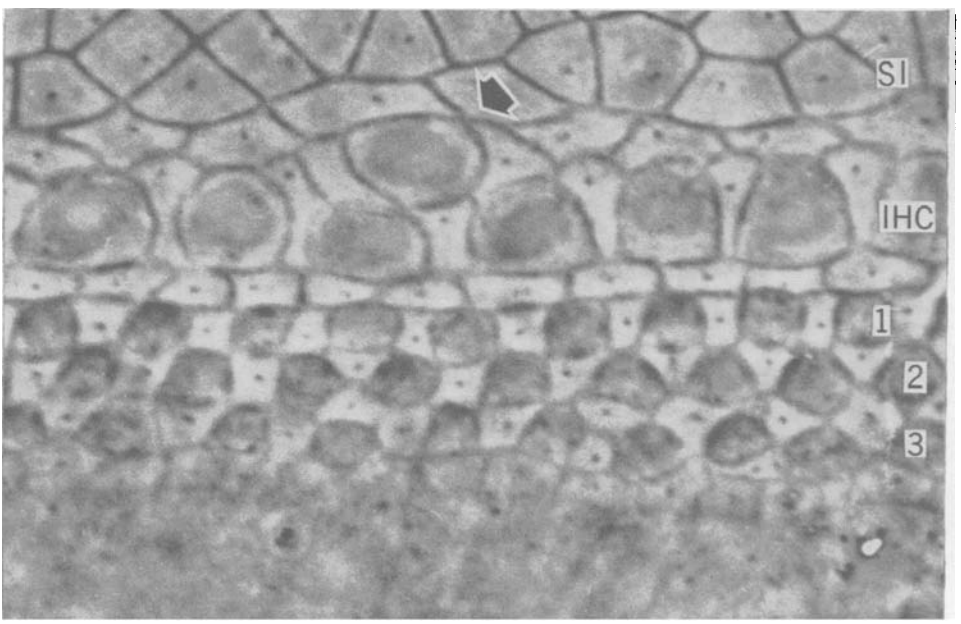


FIG. 5

Organ of Corti, same human foetus as in Fig. 4, surface specimen one coil from basal end. Note small size of and similar configuration of both sensory and supporting elements in the outer rows, indicating a less advanced stage of development than seen in basal coil (Fig. 4). In contrast the inner hair cells (I.H.C.) are fairly well developed. An extra cell can be seen here (arrow). (Magnification ×1,875.)

At birth and thereafter there is little or no change in the cellular pattern of the organ of Corti. Although the developmental pattern attains stability a change in this pattern may occur and in fact does so with age. There occurs a loss in both the sensory and supporting elements. As early as at the end of the second decade the loss of sensory cells is noticeable (Fig. 8). At old age the loss of sensory cells may be

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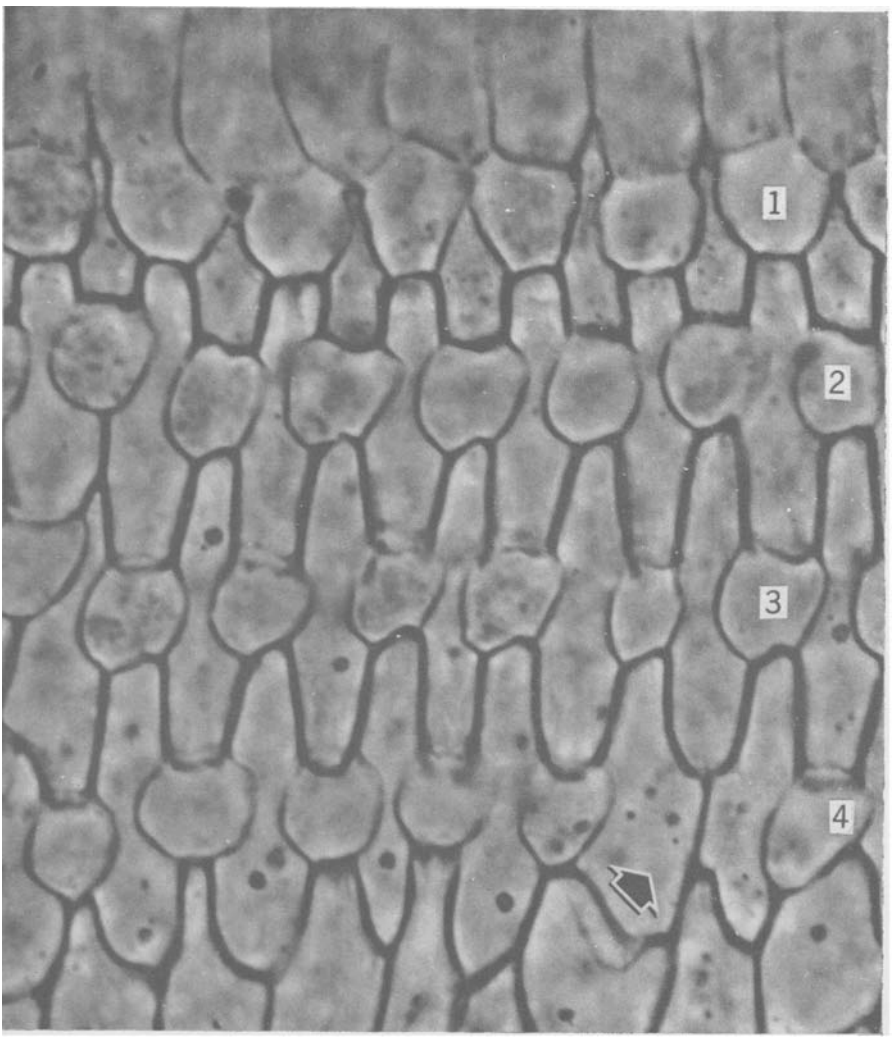


FIG. 6

Organ of Corti (human foetus, 32 wks.) surface specimen two coils from basal end showing four regular rows of outer hair cells (1, 2, 3, 4). Note absence of one sensory cell in the fourth row (arrow). (Magnification ×1,560.)

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pronounced and is particularly conspicuous in the basal coil (Fig. 9). In addition there often occurs a degeneration of hair cells and nerves in the apical coil (Fig. 10). Although degeneration of nerves and ganglion cells in the apical coil of the cochlea have been described earlier (Guild, 1935; Covell and Rogers, 1957; Lindsay and v. Schulthess, 1958; Bernstein and Schuknecht, 1967) no mention of a specific degeneration of sensory cells in this region has been noted. It is possible that such a change in the pattern of the cell population at the apical region of the cochlea may have been overlooked. That a degeneration of sensory cells does occur in this region in old age may be seen clearly by examining a surface specimen and may further be recorded by the construction of a cochleogram (Fig. 11).

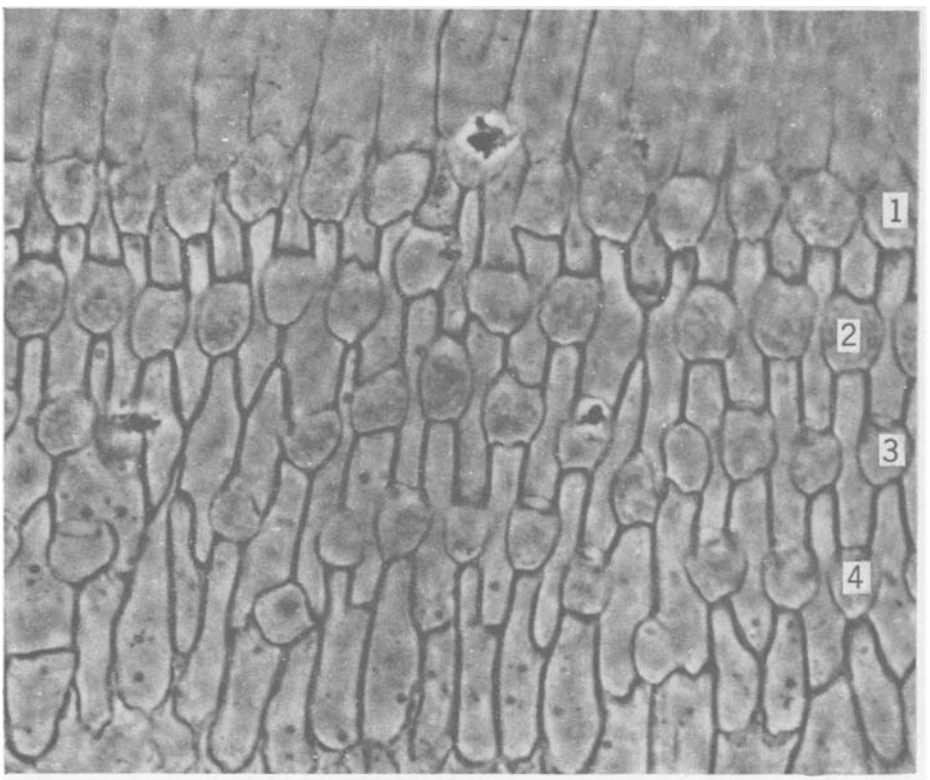


FIG. 7

Organ of Corti (human foetus, 32 wks) surface specimen two coils from basal end showing a modified pattern from that seen in Fig. 6. Note loss of regularity in the general arrangement of outer hair cells. (Magnification ×940.)

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The Human Cochlea During Development and Ageing

There exist variations in the normal pattern of sensory cells which apparently appear to have no bearing on the hearing. One such variant is illustrated in Fig. 12. It is also possible to study abnormalities in the cellular pattern in the organ of Corti and in individual sensory cell in congenitally malformed ears.

Particular interest has been devoted to the study of the interrelation between the nerves in the spiral osseous lamina and the cellular population throughout the cochlea in various kinds of hearing losses. In cochleas prepared as outlined above, it is possible to observe not only the gross appearance of structure but also the nerve bundles in the spiral osseous lamina and the organ of Corti throughout all coils (Fig. 2). Normally

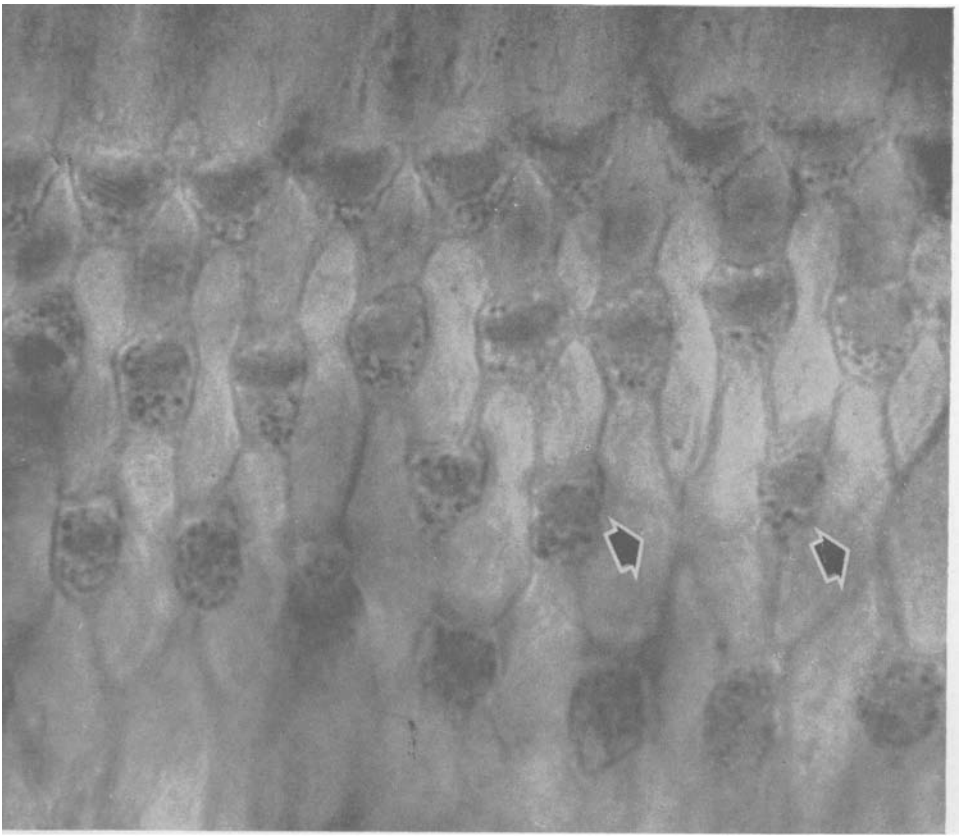


FIG. 8

Organ of Corti (male, 18 yrs.) surface specimen two coils from basal end showing a fairly regular pattern of outer hair cells. Note absence of two sensory cells in the third row (arrows). (Magnification ×1,900.)

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the density of the nerve bundles in the spiral osseous lamina is rather uniform (Fig. 13).

Under certain forms of impaired hearing associated degenerations occur in the nerves and in the organ of Corti (Figs. 14, 15). These degenerations may be associated with a corresponding hearing loss for pure tones but cases have been observed where the hearing loss and the extent of degeneration is difficult to explain. Occasionally changes do occur in these structures with no corresponding hearing loss. These changes may be single or multiple (Fig. 16). Macroscopically, regional or segmental absence of nerves in the spiral osseous lamina may (Figs. 16, 17) or may not be accompanied by an absence of a part of the organ of Corti in the same segment. In the latter instance, however, it is found that when the specimen is subjected to higher magnification corresponding change in



FIG. 9

Degenerative changes in the organ of Corti (male, 62 years), surface specimen one coil from basal end showing a rather pronounced loss of outer hair cells. Intact cells appear dark. (Magnification ×1,400.)

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the cellular pattern of the organ of Corti becomes obvious. This is also true of old age where a degeneration of nerve fibres may result not only in the regional absence of nerves but also in a diffuse rarefaction of nerve fibres whereby the nerve bundles may appear less dense (Fig. 16). Although macroscopically the organ of Corti may appear intact, its cellular pattern microscopically, however, shows a corresponding loss in its sensory elements throughout the cochlea.

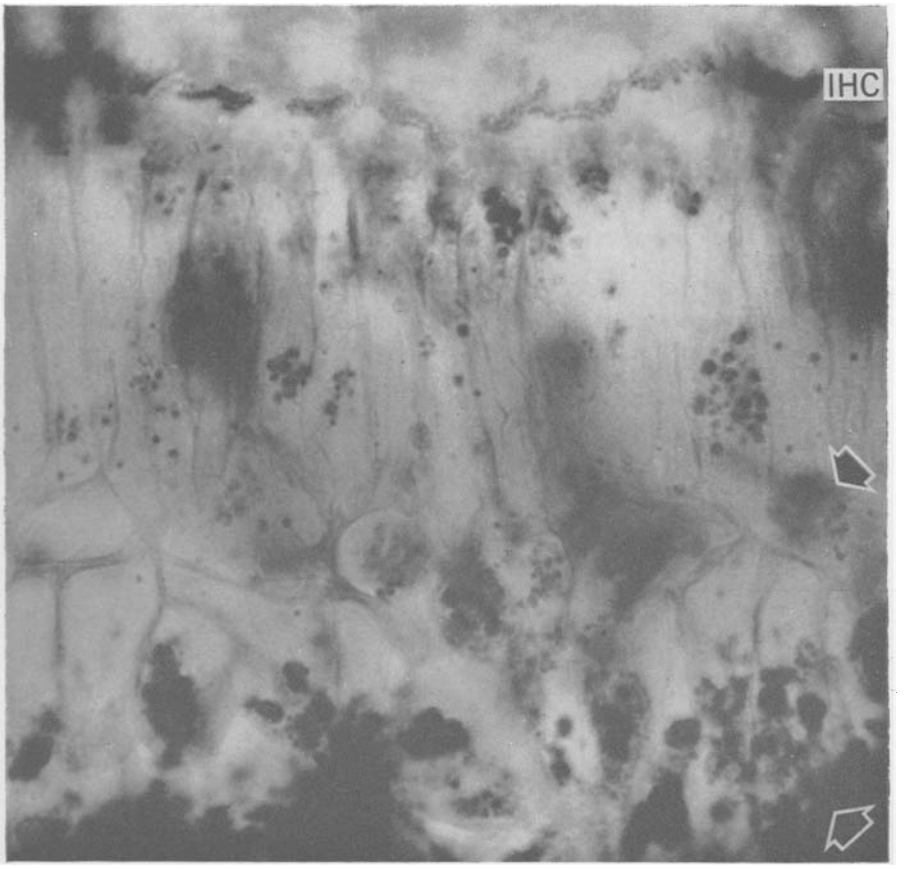


FIG. 10

Degenerative changes in the organ of Corti (male, 93 years), surface specimen two coils from basal end showing a loss of all outer hair cells leaving behind an irregular framework of supporting cells (between arrows). The inner hair cells (I.H.C.) are intact: their hairs are in focus. (Magnification ×1,420.)

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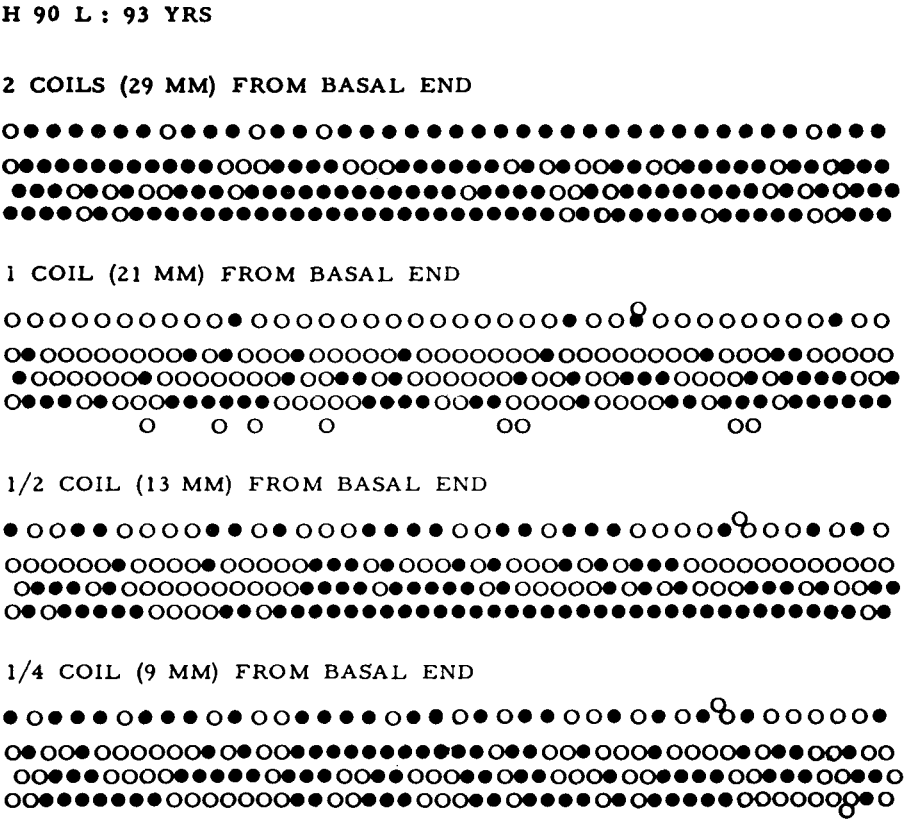


FIG. 11

Cochleogram. Black dots and circles represent degenerated and apparently normal sensory cells respectively. Note extent of apical degeneration.

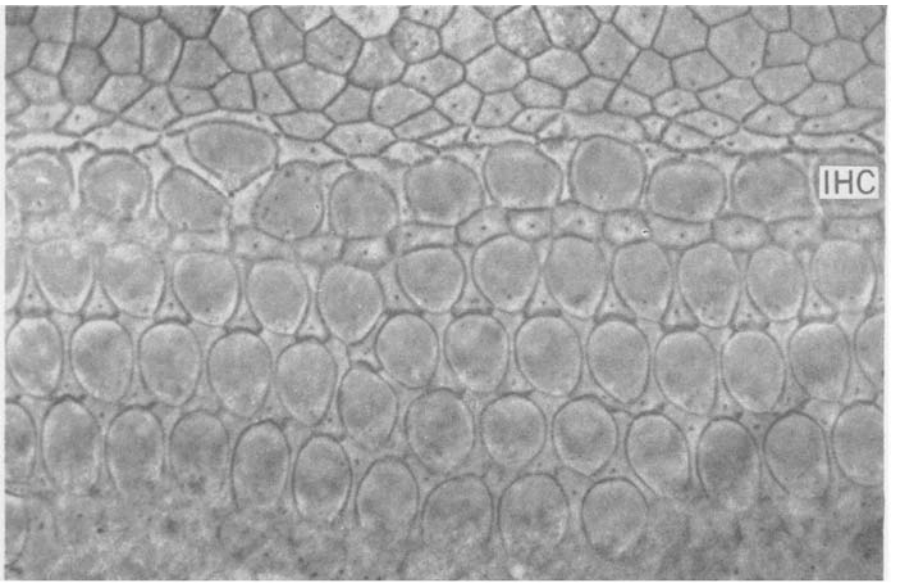


FIG. 12

Organ of Corti (human foetus, 15 wks.) surface specimen from basal coil showing a variation of the normal pattern (compare Fig. 4). Note deviation in the linear configuration of outer sensory cell rows at midfield. (I.H.C.) inner hair cells. (Magnification ×940.)

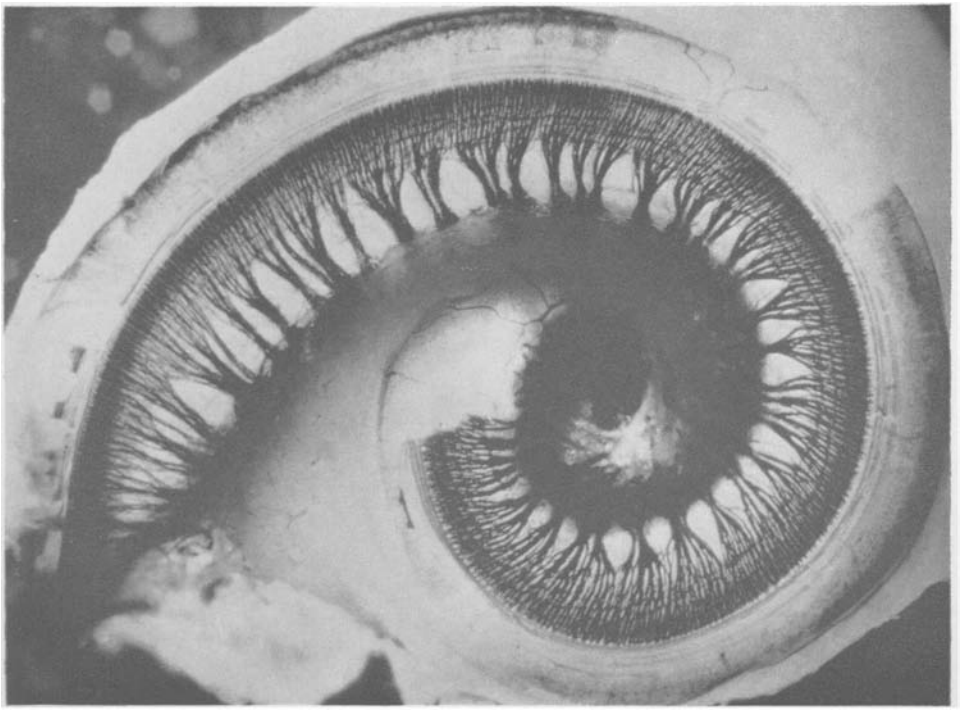
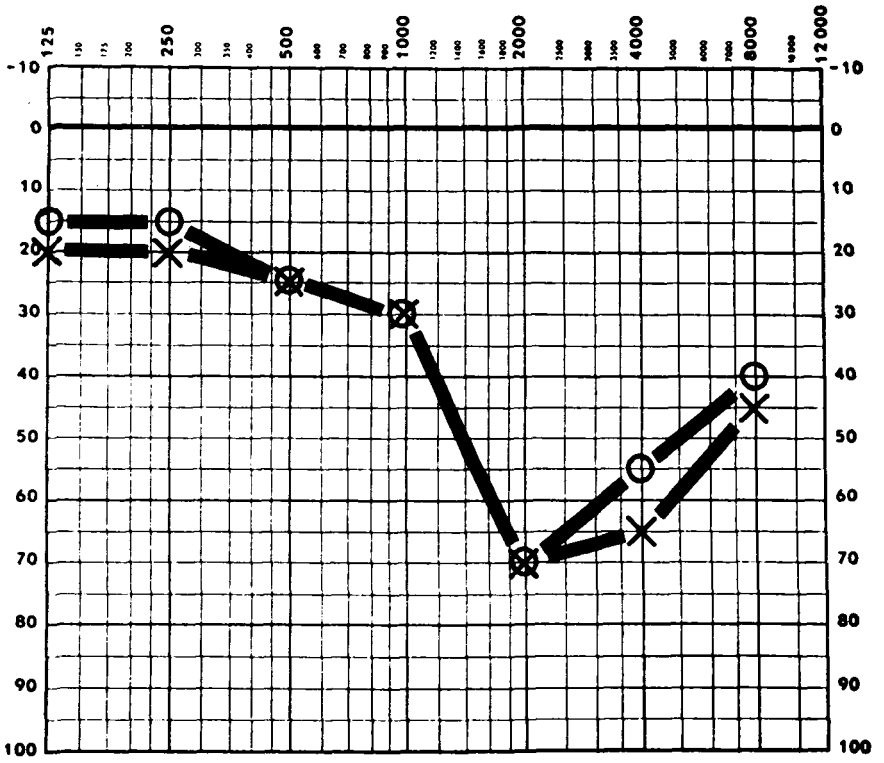


FIG. 13

Basal coil from a human cochlea as seen from above showing the normal, dense and uniform distribution of nerve bundles in the spiral osseous lamina. (Magnification ×13.)

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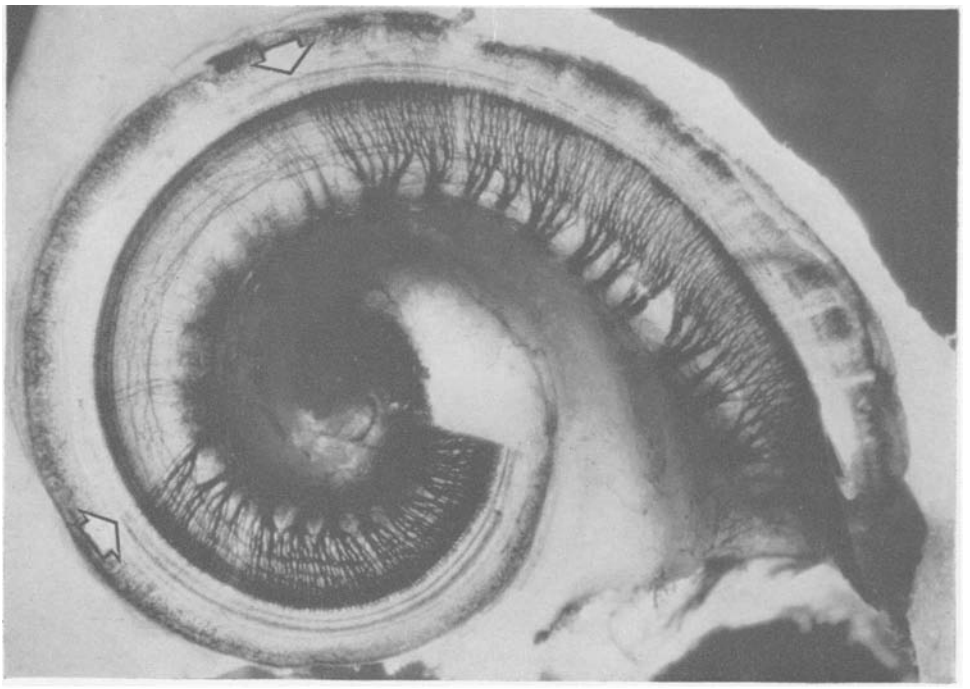
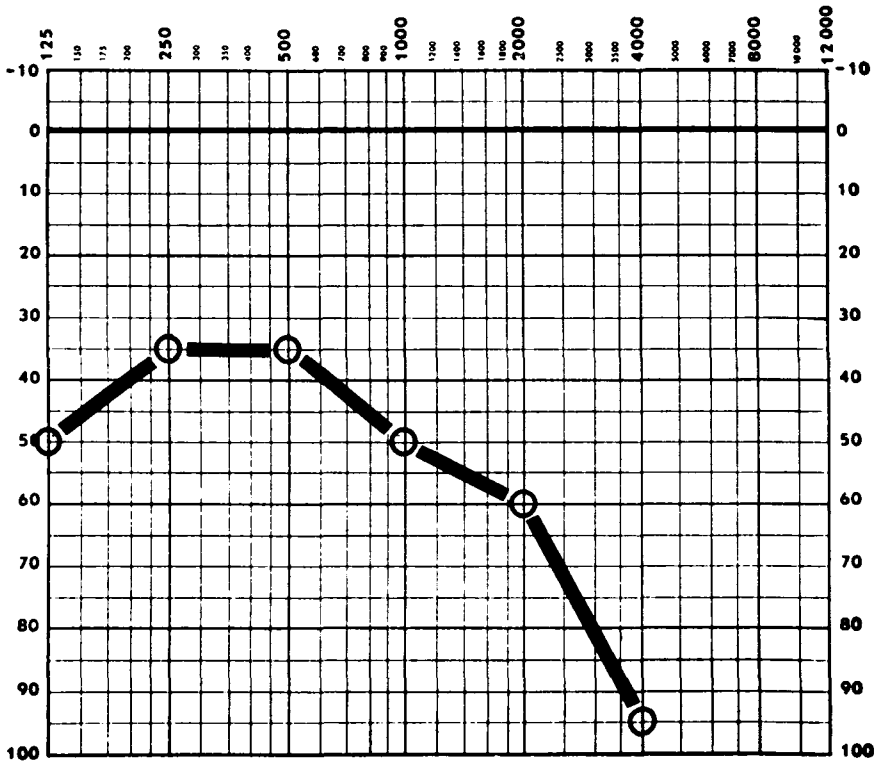


FIG. 14 & 14 A

Cochlea and audiogram from a man aged 71 exposed to high intensity noise in a sawmill for several years. Note the dip in the audiogram in the frequencies 2,000 c.p.s. to 4,000 c.p.s. The cochlea shows a complete degeneration of the nerves in the spiral osseous lamina as well as a corresponding degeneration of the organ of Corti 10·5 mm. to 14·5 mm. from the basal end (between arrows). (Magnification ×13.)

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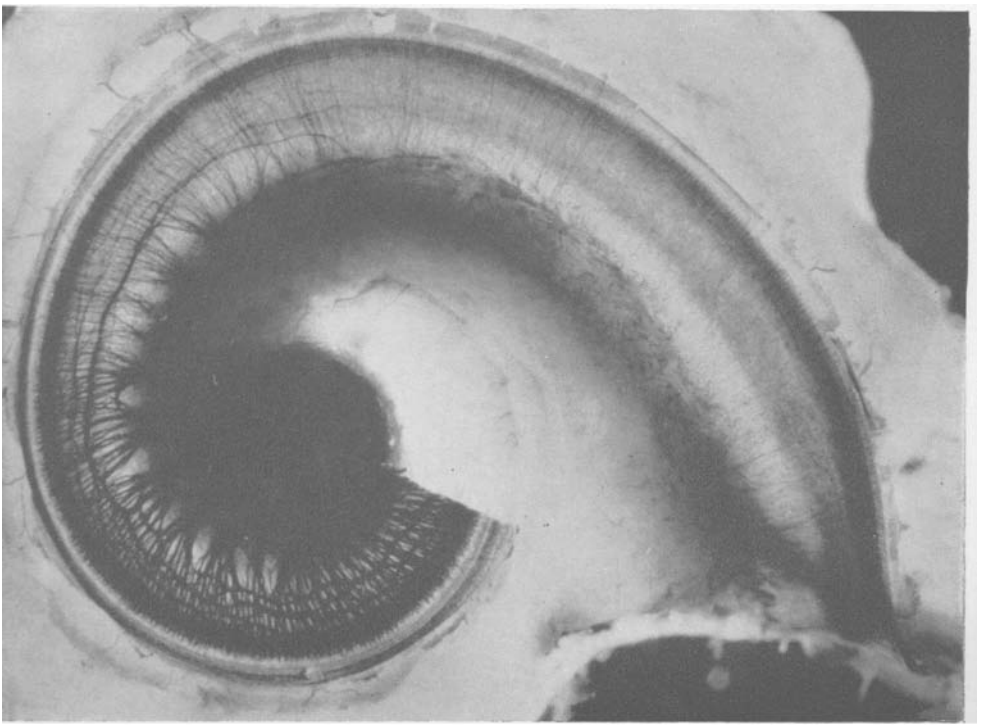


FIG. 15 & 15 A

Cochlea and audiogram from a man aged 73. The cochlea shows a complete loss of nerves as well as a loss of the corresponding segment of the organ of Corti in the lower basal coil. Further ncte the gradual encroachment of the degenerative process in the more proximal parts of the basal coil. (Magnification × 14.)

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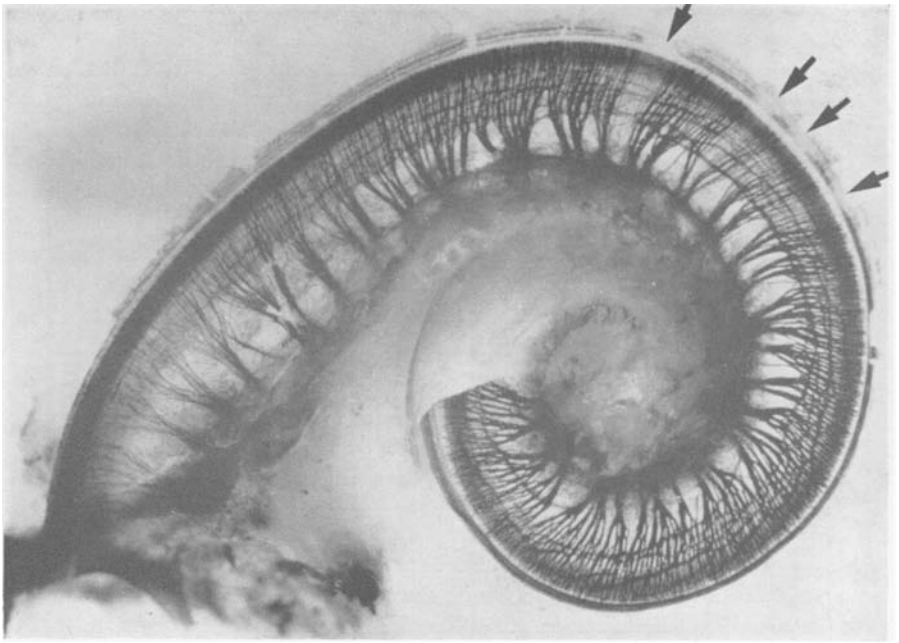


FIG. 16

Human cochlea (female, 86 years) showing an overall atrophic appearance of the nerve fibres. Moreover note the "patchy" degeneration of nerves and corresponding sensory epithelia. In addition there is a rather pronounced loss of nerves at the basal end. (Magnification $\times 13$.)

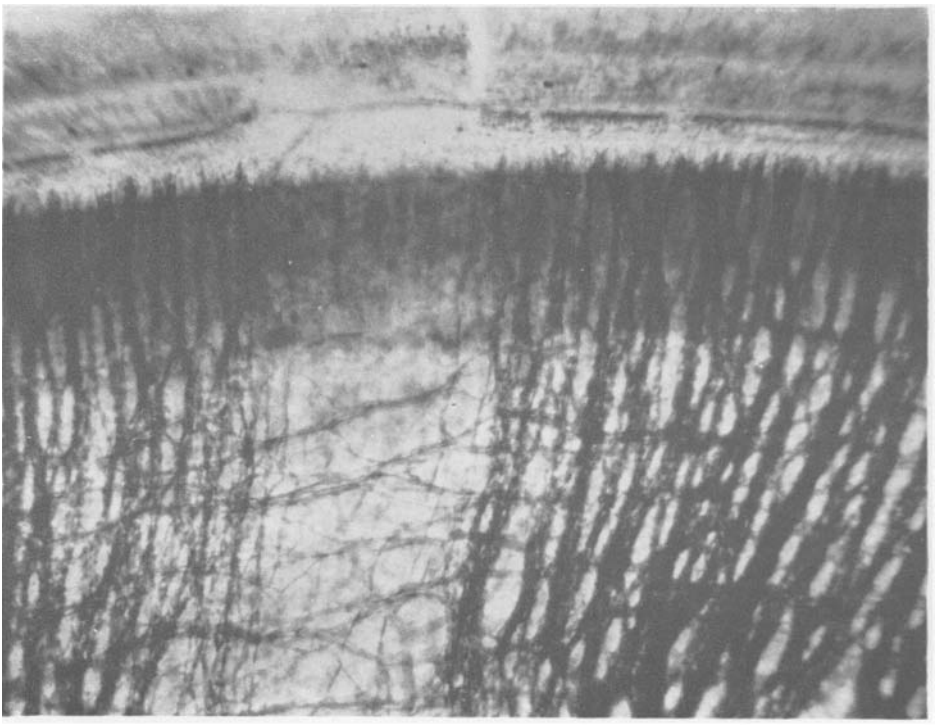


FIG. 17

"Patch" of degeneration from the same cochlea as seen in Fig. 16 in a higher magnification. (Magnification $\times 150$.)

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It is interesting to note that the literature frequently indicates that there is a normal sensory cell population in elderly people. Hearing losses may then be attributed to causes outside the organ of Corti. However, in this study it has been found that significant sensory cell losses occur in old age.

Sensory cell losses may be graphically represented as shown in Figs. 18, 19, 20.

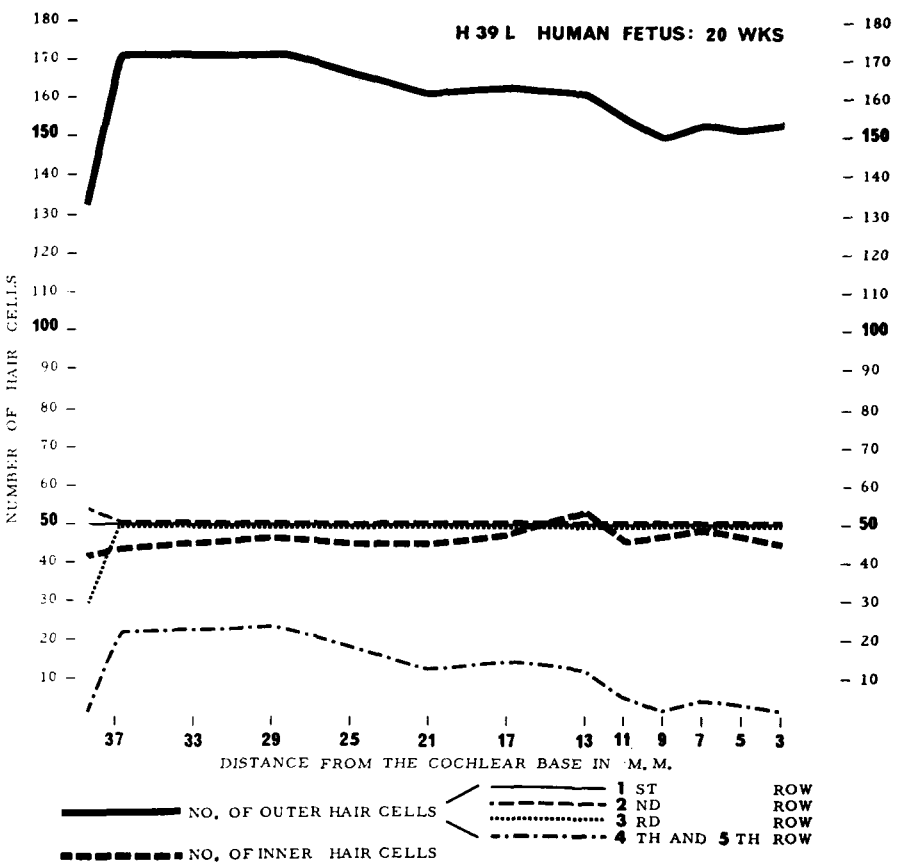


FIG. 18

A complex graph representing the density of the normal population of sensory cells in the organ of Corti (human foetus, 20 wks). The dotted, interrupted and faint lines in the figure above each represent the total number of intact sensory cells in a 50-cell count carried out on either side of a point representing a certain distance from the basal end of the cochlea. These distances are marked on the X-axis and the number of cells have been plotted on the Y-axis. The total number of outer hair cells are represented by the heavy line above.

In the human foetus there is no loss of sensory cells. The number of outer hair cells in a segment increases on approaching the apex. This is due to a more frequent appearance of fourth and fifth row of cells.

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This paper is a short comment on the study of the human cochlea during development and ageing. It will be followed by an extensive publication in preparation by the author. Some of the material here presented will be thoroughly discussed in this later publication.

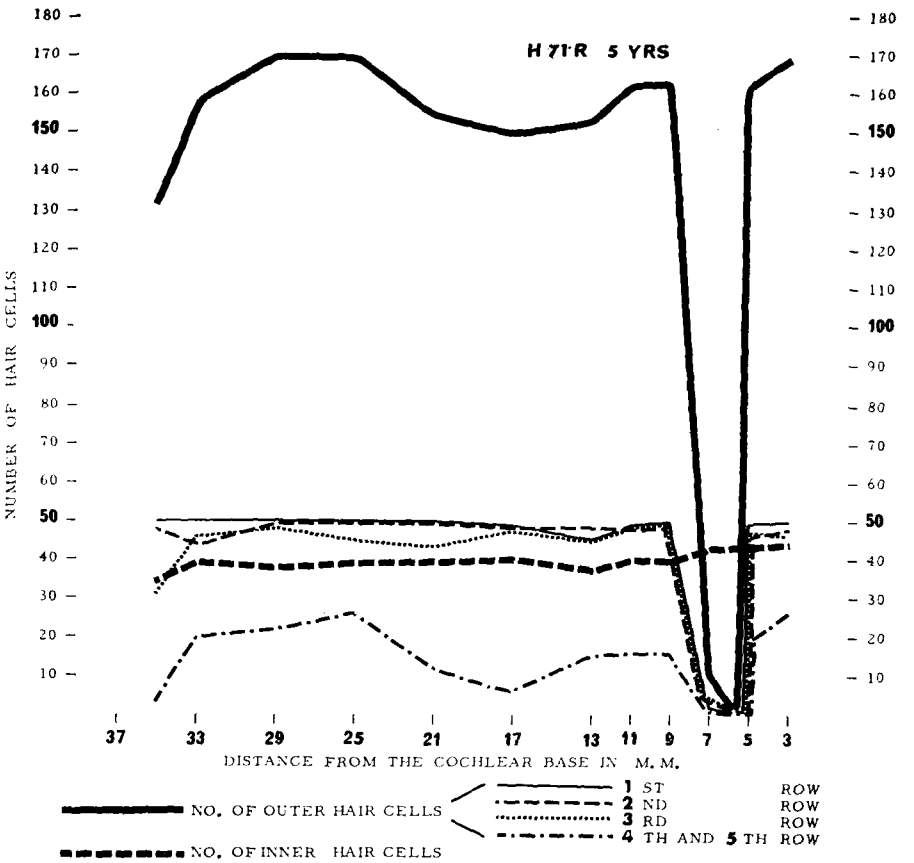


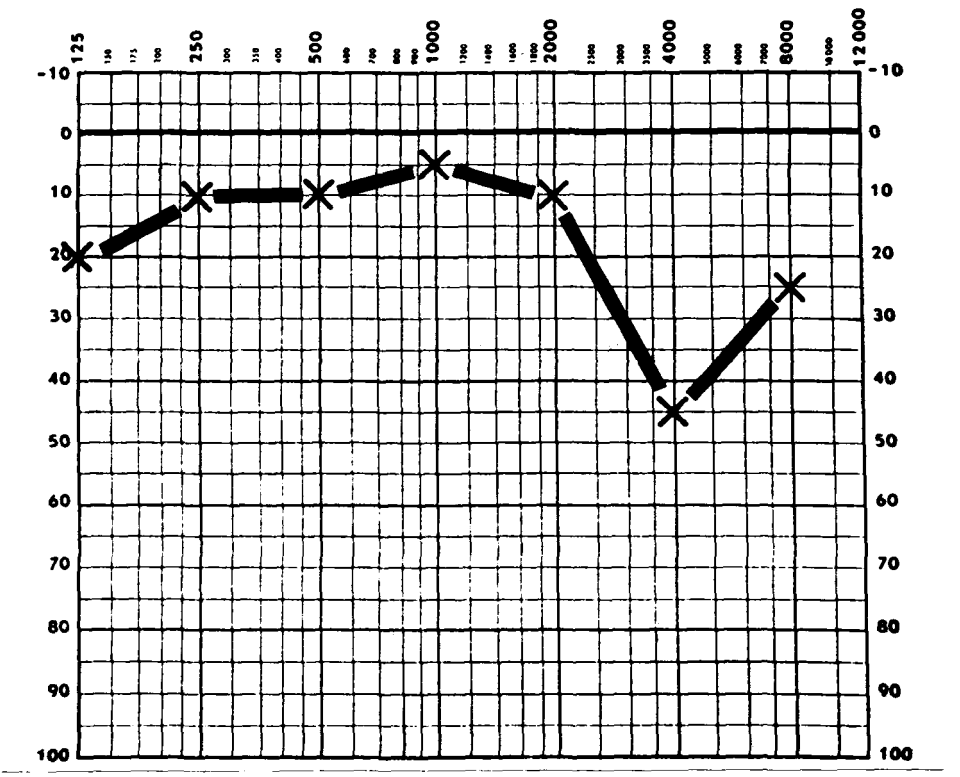
FIG. 19

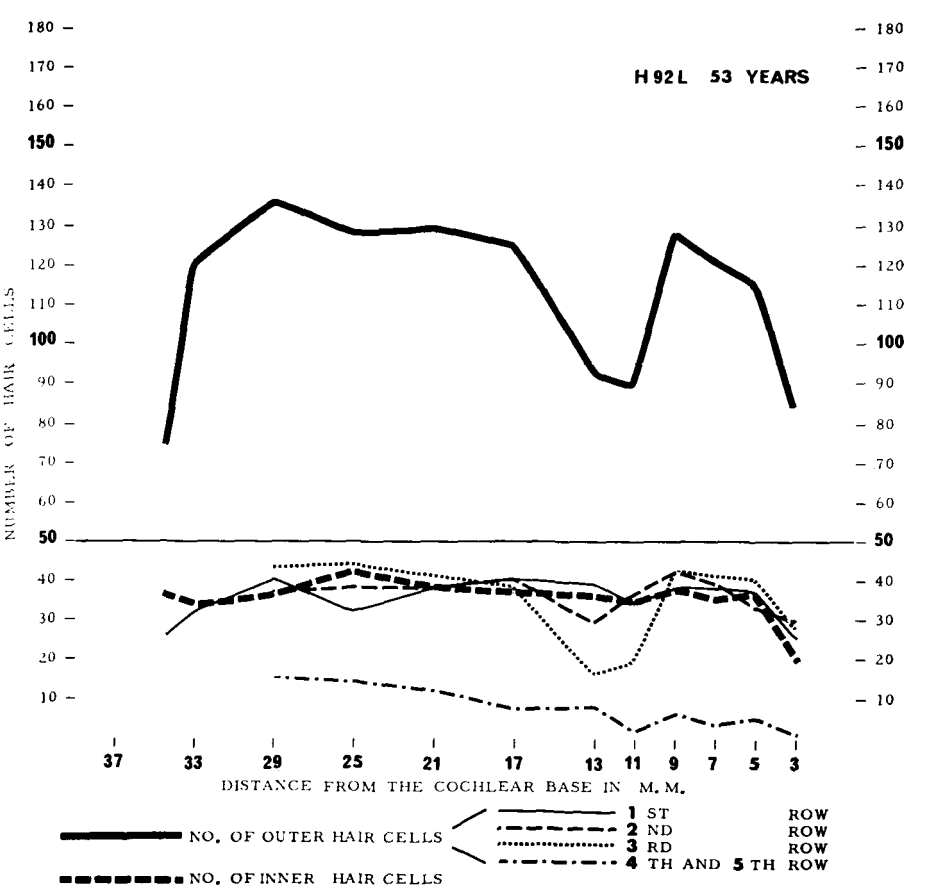
Corresponding graph to Fig. 18 representing the sensory cell population in a cochlea of a boy aged 5 who died from acute leukaemia. Note the complete and localized degeneration of outer hair cells in the lower basal coil. The inner hair cells remain intact in that region. No associated nerve degeneration was noted.

FIG. 20 & 20 A ▶

Audiogram and a graph of the cell population from a mechanic, 53 years of age, who for several years was exposed to noise in a workshop. The audiogram denotes acoustic trauma with the typical 4,000 c.p.s. dip. There is an overall reduction of the total number of outer sensory cells (compare Fig. 18). Note the dip in the graph representing a local loss in the total number of intact outer hair cells from 11 to 13 mm. This loss depends mainly on degeneration of cells in the third row as seen by the dotted graph.

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Conclusions

In this investigation special methods have been applied to a study of the human cochlea during foetal life, maturing and in ageing. Special interest has been devoted to the problems of hearing loss and cochlear damage. It has been found that it is possible even at low power magnification to observe degeneration in both sensory cells and nerves in the human cochlea. In specimens prepared without any sectioning it is equally possible to make a quantitative estimate of such cochlear damages throughout all coils.

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