Histological Study of Auditory and Static Ganglia
in Earlier Stage of Human Embryo.

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The fine structure of the cerebrospinal ganglia has been studied by many researchers in the past, by DOGIEL (1908), LENHOSSÉK (1893), RETZIUS (1892—93), CAJAL (1904), KÖLLIKER (1896) and others, and more recently STÖHR (1928), YAMASHITA (1939) and SETO (1951) have succeeded in throwing much light on the problem, but most of these studies have taken the spinal ganglia as object, studies on the cerebral ganglia being much fewer in number. In particular, the histology of the stato-acusticus ganglia have been taken up only by rather a small number of researchers, such as RETZIUS (1892—93), AYERS (1893), LENHOSSÉK (1893), CAJAL (1904), BIELSCHOWSKY and BRÜHL (1908). In summarizing the results of these studies, however we find that their contents are limited to the observation that these ganglia are composed merely of bipolar nerve cells. AYERS (1893) alone has reported the existence of multipolar nerve cells beside the bipolar ones in the ganglion acusticum, though it is doubtful whether he used human or other animal specimens in his study and he failed to illustrate his remarks with supporting pictures. He also does not explain the form and nature of such cells. As for ontogenic studies of the cerebrospinal ganglia, the number is even much smaller, and almost no reliable achievement has ever been published in this field, except in the recent study by MIKAMI (1953) of this laboratory on human spinal ganglia, which is a feat worthy of special mention.

In face of such a situation, I was deeply intrigued by a scrutiny of the development of the nerve cells in the auditory and the static ganglia and a comparative study of my observations with those of MIKAMI (1953). I took my materials from human embryos of one, three and five months, fixed them in 10% neutral formol for a long time, cut them into a series of 30—40μ frozen transverse sections of the head including the internal ear and stained them with the SETO's impregnation in use at this laboratory. The very beautiful series of preparations thus obtained I subjected to close microscopic examination, and succeeded in gaining many individual observations outlined in the following.
I. Individual Observations.

What greatly struck me in this study is the fact that the nerves, especially the peripheral nerves, are so enormously better developed than all other organs in the human embryos of the early stage. This fact must have interested all neurologists who have ever studied the nervous system ontogenetically and MIKAMI (1953) also speaks of his emotion on seeing the admirable development of the peripheral nerve system in his report of his above mentioned study. In my sections, I saw that the auditory and the static ganglia were filled with very well-developed nerve cells and were of surprisingly large size, the nerve bundles running into and out of these ganglia being composed of stout fibres strongly silver-affine and staining dark purple, which end in forming intrapithelial fibres of complex structure in the specific epithelium (Figs. 1, 2, 3 and 4).

Fig. 1. Distribution of n. vestibuli for crista ampullaris and macula utriculi of a human embryo of one month. g ganglion vestibuli. SETO's silver staining. ×80, reduced to 1/2.

Fig. 2. Ganglion spirale cochleae of a human embryo of one month. Same staining. ×80, reduced to 1/2.
The nerve cells in the ordinary cerebrospinal ganglia of human adults may be classified into the major and the minor types in size and by the number and the form of the courses of the nerve processes sent out by each cell into the simple unipolar, the complex unipolar, the simple bipolar, the complex bipolar, the multipolar, the fenestrated and the end-plated types, as shown by YAMASHITA (1939) in his study on the semilunar ganglion. This classification was also confirmed by MIKAMI (1953) in his study on the embryonic spinal ganglia, though of course in a more infantile evolution.

It has been almost unanimously affirmed that both the auditory and the static ganglia in human adults contain only bipolar nerve cells. The accepted opinions have been that in these ganglia of animals are found many peculiar medullated ganglion cells not to be found in any other cerebrospinal ganglia but in man only in the auditory ganglion in rare cases and never in the static ganglion (MÜNZER 1936, SCHARF 1952), that there are some peripheral cell nuclei around the nerve cells, origi-
nating in the SCHWANN's nuclei and corresponding to the mantle cell nuclei of the ordinary cerebrospinal ganglia, in short, that the sensory nerve cells in the auditory and the static ganglia are morphologically much simpler than those in other cerebrospinal ganglia.

According to the hitherto current ontogenetic informations on the nerve cells in the cerebrospinal ganglia in general, these cells are represented in embryonic life by bipolar cells in their infantile formation, which go over into unipolar cells by the gradual fusion of both of the nerve processes in later stages of growth, the cells in the auditory and the static ganglia being usually cited as examples of the infantile bipolar type remaining unchanged post-natally. This opinion, however, must be looked upon as very irrational from the physiological point of view, for these nerves should belong to the class of highest cultural development of all sensory nerves. Furthermore, since the above ontogenetical hypothesis has been exploded by the recent study by MIKAMI (1953) on the ontogenesis of the spinal ganglia, it is natural to assume that the bipolar cells in the auditory and the static ganglia are nothing infantile in their development, but represent some characteristic formation with an important physiological bearing.

The results of my minute study of the sensory nerve cells in the auditory and the static ganglia in my embryos of the earlier stage permitted me to supplement some new observations to the current information about the adult human auditory and static ganglia that they contain only simple bipolar cells (BIELSCHOWSKY and BRÜHL 1908 etc.) and it is of great interest that I could point out the existence of unipolar and multipolar cells in these ganglia.

The cells in the auditory and the static ganglia (especially in the latter) can be generally classified into the three types of bipolar, unipolar and pseudoapolar cells. This classification was also found applicable by MIKAMI (1953) in his study, but the rate of occurrence of these three types is quite evidently different, the majority being taken up by bipolar cells in the auditory and the static ganglia, while it consists of unipolar cells in the spinal ganglia. The course of the nerve processes are very simple, as MIKAMI (1953) has found in his specimens, and no such intricate courses shown by the so-called complex type cells in the cerebrospinal ganglia of human adults were ever found. It is an interesting finding that such multipolar and fenestrated cells as found in other cerebrospinal ganglia in human adults (YAMASHITA, 1939) and embryos (MIKAMI, 1953) were not rarely observed in the static ganglion of a young embryo, too.

The pseudo-apolar cells are very numerous in a first month embryo, in my auditory and static ganglia as well as in spinal ganglia (MIKAMI,
1953), and almost all the nerve cells are of such a nature. However, in third and fifth month embryos, the number of these cells greatly diminishes, the majority passing over into bipolar cells. Thus, the pseudo-apolar cells represent the most infantile type of nerve cells, in the auditory and the static ganglia as well as in other cerebrospinal ganglia.

These cells, as shown in Figs. 5 and 6, have each large round cell nucleus, and the development of the surrounding protoplasm is very weak, so that the cells look as if they were composed merely of cell nuclei. The nerve processes belonging to such cells could not be detected even under oil immersion, but as very conspicuously silver-stained stout sensory fibres are seen penetrating the ganglia, it is obvious that these fibres originate in the pseudo-apolar cells therein, but the parts of the processes where they emerge from the cells are not yet developed to acquire silver-affinity, due to the immaturity of the nerve fibrils, as in the protoplasm of the nerve cells, so that these cells look as if they were apolar. This interpretation of the nature of these cells is in agreement with that of MIKAMI (1953), and the name "pseudo-apolar" to these cells is quite appropriate.
There is no doubt that these pseudo-apolar cells develop into the underdescribed polar cells upon maturation of the nerve fibrils in the incipient part of the processes and the cell protoplasm later on. In a third month embryo, the pseudo-apolar cells decrease greatly in number and numerous bipolar cells take their place, but uni- and multipolar cells also make appearance, though in a limited quantity, and in rarer cases even fenestrated cells. So the nerve cells in the auditory and the static ganglia originate in the earlier stage of embryonic life already, with bipolar cells as the basal type, but a part of them also becomes uni- and multipolar cells. Inferring from the results of studies by YAMASHITA (1939) and MIKAMI (1953), these types of cells apparently continue their existence into the postnatal life without change in nature.

As shown in Figs. 7 and 8, not only do the nerve cells in a third month embryo become polar cells in general, but the cell nuclei,
which had been nearly undefinable in a first month embryo so develop as to be distinguishable into the two sizes of major and minor. The cells that contain major nuclei are larger in size themselves than those with minor nuclei, and the nerve cells in the auditory and static ganglia, as in the other cerebrospinal ganglia in general, become distinct as major and minor cells. The major cells largely predominate in number and the nerve fibrils in them are earlier and better developed than in the minor cells. These two types in the ganglia of the inner ear are arranged extremely irregularly, such definite arrangements as seen in other cerebrospinal ganglia (MIKAMI 1953) being entirely absent. Such observations become even more evident in a fifth month embryo. Apolar cells becoming nearly unobservable at this stage. Myelins, however, are as yet unformed (Fig. 9).

Beside the above findings, we find mantle cell nuclei, which were scarcely observable in a first month embryo, appearing in a third month embryo. The number, however, of these nuclei is far smaller than in the other cerebrospinal ganglia, and the number attains a very limited increase even in a fifth month embryo. According to MIKAMI (1953), the increase of mantle cell nuclei is in proportion to the complication of the courses of the nerve processes running through the mantle cell plasmodium. The size of the nerve cells in the auditory ganglia (Fig. 10) is smaller than the cells in the static ganglia, the ratio of the size being

![Fig. 9. Bipolar ganglion cells seen in ganglion vestibuli of a 5th month human embryo. Same staining. ×1000, reduced to 2/3.](image)

![Fig. 10. Ganglion spirale cochleae of a 3rd month human embryo. Ganglion cells are almost of bipolar nature. Same staining. ×1000, reduced to 2/3.](image)
The bipolar cells representing the majority of the nerve cells in the auditory and the static ganglia have two processes each that emerge through conical bases from the cell bodies. The two processes generally emerge from opposite poles of the cell body, but in some cases they are sent out from very closely neighboring points (Figs. 9 and 10), and run very simple straight courses. One of the two processes extends peripherally and the other centrally but both consist of smooth-surfaced fibres showing little change in size.

According to CAJAL (1904), LENHOSSEK (1893) and others, the peripheral one of the two processes is stouter than the central one, but BIELSCHOWSKY (1908) states that the former is thinner in size than the latter. My observations showed that, in agreement with those of bipolar cells observed by YAMASHITA (1939) in the semilunar ganglion of human adults and by MIKAMI (1953) in embryonic spinal ganglia, there is no regular difference observable in the general size of the two processes. In fact, in some cases, the peripheral process is thicker than the central while sometimes the latter is thicker than the former. In concluding my description on the cell processes, I may mention the surprising fact that, to my great interest, I have encountered, though in extremely rare cases, a variation of bipolar cells of which both the processes bifurcated in Y shape at a short distance from the cell body.

I have detected unipolar cells in the static ganglia, though in a very small quantity. As such a fact has not yet been reported by any researcher, I was greatly surprised and interested. As clearly shown in Figs. 11 and 12, a single process emerges from the cell body through a conical protuberance, and somewhat in a different manner from those in embryonic spinal ganglia (MIKAMI 1953), branch out in T or Y shape soon after emerging, the two branches proceeding peripherally and centrally each. Both branches are of smooth-surfaced fibres but no rule is observable on the relative size of the two, as with the processes from bipolar cells.

That multipolar cells
are found, though in an extremely small quantity, in the adult human cerebrospinal ganglia has been discovered by DOGIEL (1908), LENHOSSEK (1893), CAJAL (1904), RANSON (1912) and YAMASHITA (1939). Especially the last mentioned has clarified that these are not of sympathetic but of purely sensory nature and are of normal presence, and supposed that they are in existence since the earliest stage of human life. This supposition was confirmed by the ontogenetic study on the spinal ganglia in third and fourth month embryos by MIKAMI (1953), who has detected a very small number of multipolar cells clearly distinct from vegetative, especially, sympathetic nerve cells in form, and assumed them to be normally formed sensory nerve cells. Also he pointed out that fenestrated cells, which are looked upon as a variation of multipolar cells, are formed in the early stage of embryonic life already.

However, there have been no report to date that multipolar cells exist in the auditory and the static ganglia. AYERS alone, as cited above, has reported that he has found some multipolar cells of unknown nature in the auditory ganglia, though he failed to substantiate his finding with any illustration. The author of this paper, however, succeeded in detecting in third and fifth month embryos a considerable number of multipolar cells, especially in my sections of their static ganglia, similar in structure to those found by MIKAMI (1953) in the spinal ganglia of early embryos. These cells show a marked tendency to develop in groups (Figs 7, 8 and 14), and in general are large-sized cells with three to six processes each (Figs. 7, 8, 13 and 14). The processes come forth from the surface of the nerve cells at very irregular inter-spaces, mostly through conical bases. Two long processes per cell run

![Fig. 12. An uniolar ganglion cell and 2 bipolar ganglion cells seen in ganglion vestibuli of a 5th month human embryo. Same staining. ×1000, reduced to 2/3.](image-url)
cesses running either peripherally or centrally or in both directions simultaneously are not infrequently found, and no one has ever described the existence of such unusual types of multipolar cells in any other cerebrospinal ganglia. The quin-polar nerve cell illustrated in the lower part of Fig. 7 also belongs to such a variation of multipolar cells. In many cases, a long process sends out minute collaterals at a short distance from the cell body. Here also, as with bipolar cells, no rule is established in the relative size of the peripherally and centrally running long processes. As a variation of multipolar cells, a very small number of fenestrated cells which have peripherally and centrally as usual, but the other processes are short, run into the circumferential area and end freely after or without branching, as shown in Fig. 13.

As to the courses of the processes, however, some multipolar cells show very different types from the above described ones. For example, in the quadripolar cell shown at the center of Fig. 7, the four nerve processes are all long and stout, of which two run both peripherally and the other two both centrally. In another multipolar cell shown in Fig. 14, one of the long processes extends peripherally but other two both run centrally. It is of interest that multipolar cells with more than one long pro-

Fig. 13. A sexpolar and many bipolar ganglion cells in ganglion vestibuli of a 3rd month human embryo. Same staining. ×1000, reduced to 2/3.

Fig. 14. 3 tripolar and 2 bipolar ganglion cells seen in ganglion vestibuli of a 5th month human embryo. Same staining. × 1000, reduced to 1/2.
been known to exist in spinal ganglia has been found by the author in the static ganglia of third and fifth month embryos. As shown in Fig. 15, the stout process coming out from the left-hand side of the nerve cell soon branches out into several rami, of which one fine fibre returns to the mother cell body describing an arc, thus forming a window within the arc. Another interpretation may be that a fine fibre emerging from the cell body forms the window by anastomosing with a fine branch of the thick long process.

In conclusion, I report that no nerve cell with end plates has been found in either the auditory or the static ganglia.

II. Summary.

I have succeeded in supplementing the currently accepted observation that only simple bipolar cells are found in the auditory and the static ganglia with a few new findings in my recent ontogenetical study on the subject.

The nerve cells in the auditory and the static ganglia in earlier stage of human embryo, especially in the latter, are mostly bipolar, but there are also some multipolar, fenestrated and unipolar cells in them, the most primitive formation of all the types being represented by pseudo-apolar cells.

The pseudo-apolar cells, which represent in a first month embryo the prototype of all the other above mentioned cells, decrease rapidly as the embryo grows to third and fifth months, the majority being...
transformed into bipolar cells. In a pseudo-apolar cell, the development of the protoplasm surrounding the cell nucleus and the incipient parts of the processes emerging from it being very low as yet, the nerve fibrils therein are too immature to be silver-affine, so that the cell itself shows the appearance of apolarity in a preparation. Later on, with the maturation of the above mentioned parts, these cells take the form of polar cells.

When an embryo reaches the age of three months, the nerve cells begin to show the distinction of major and minor types. The larger cells predominate far over the smaller ones in number, and the development of nerve fibrils is more rapid and powerful in the former. In a fifth month embryo the above outlined observations become more apparent, almost no pseudo-apolar cells being found persisting. The nerve cells in the auditory ganglia are smaller than those in the static ganglia, the proportion of size being approximately 2 to 3.

Of the bipolar cells occupying the numerical majority in the cells of the auditory and the static ganglia, the two nerve processes generally start from opposite poles of the cell body, but in many cases, the points of emergence are very closely situated. One of the two processes runs peripherally and the other centrally. The size of the two processes is different in most cases, but no regularity is observable in their relative thickness. It is very interesting that some bipolar cells are found, of which both the processes bifurcate in Y shape, soon after emergence.

A small quantity of unipolar cells are found contained in the static ganglia. These are somewhat different from those observed by MIKAMI (1953) in the spinal ganglia of early embryos, in that the single process emerging from a pole of such a cell bifurcates in T or Y shape at a short distance from the cell and the two branches run peripherally and centrally respectively.

A considerable number of multipolar cells, similar to those found by MIKAMI (1953) in the spinal ganglia of embryos in the earlier stage, is found in the static ganglia. These multipolar cells tend to appear in groups, belong to the major type of nerve cells and send out from three to six processes per cell. The processes emerge from irregularly spaced points on the cell surface, and in general two of the processes are long, each running peripherally and centrally; the other short processes extend circumferentially and end freely after or without branching. Beside the above usual type, multipolar cells are not rarely found that are somewhat differently formed. For example, in some quadripolar cells, all the four processes are long, two of them running peripherally and the others centrally; in some tripolar cells, one of the long processes runs peripherally and the other two centrally. In short, there are found
multipolar cells that send out more than one long processes simultaneously running peripherally or centrally, in rather frequent cases.

As a variation of multiform cells, I succeeded in proving the existence of fenestrated cells, though very sparsely, in the static ganglia of embryos in earlier stage, but no cells provided with terminal plates have ever been found in either the auditory or the static ganglia.

内容自抄

人胎生初期の聾及平衡神経節特に後者内の神経細胞は多くは二極細胞であるが、他と同様多極細胞、有窓細胞並に単極細胞として表われ、又最幼若型は何れも偽無極細胞で表われされる。

偽無極細胞は１ケ月胎児では殆んど絶しての細胞に当てはまるが、3ケ月及5ケ月胎児になるとは著しく減少、之に代って大多数は二極細胞に移行する。偽無極細胞とはその原形質及び神経突起の起始部内の神経原線維が未熟で好篤性を示すに至らない為に恰も無極性であるかの様に見える細胞のことである。

3ケ月胎児では神経細胞は大小2種に区別され、大細胞は小細胞よりも多数存し、後者に劣ずるより神経線維の発達良好且つ早期に現われる。5ケ月胎児では両細胞の判別一層明瞭となり、此時期では無極細胞は殆ど見られなくなる。尚お聾神経節内細胞は平衡神経節内細胞よりも小型である。

両神経節に於ける多数を占める二極神経細胞の末梢性及び中枢性両突起は何れも表面平滑な太さの変化を示さない線維で表わされるが、然し両者間には数々太さの差異が認められる。但し何等法則的なものではない。尚両突起共細胞体を離れて同もなく更にY字状に2分する二極細胞も稀ならず認められる。

平衡神経節内に少量に単極細胞が発見される。之は1条の神経突起が細胞から出て間もなく末梢性及び中枢性線維にT又はY字状に分歧する事に依り表わされる。

平衡神経節内に稀ならず発見される多極神経細胞は集合的存在の傾向を有し、一般に大型細胞に属し、3－6条の神経突起を出す。神経突起の中2条の長い突起は夫々末梢及び中枢方に進むが、他の小突起は細胞周辺に非分歧性に又は単純な分歧をなして遊離に終る。尚特殊多極細胞として其神経突起が何れも末梢性又は中枢性に延びる長突起から成る場合も認められる。

多極細胞の1異型としての有窓細胞を3ケ月胎児の平衡神経節内に於だ
稀ではあるが証明する事が出来た、然し終末板所有の神経細胞は発見されなかった。

References.