Microscopical Study of Oculomotor Nucleus
in Human Adult

I Report

By

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Many histological studies on the oculomotor nucleus in man have been reported of old, but most of them were carried out with general staining methods, scarcely any one of them being done with special staining methods for neuro-fibrils. Then, I took my materials from 3 adult midbrains, fixed them for a long time in 10% neutral formol, and upon slicing one of them into transversal and two of them into sagittal 40μ frozen sections, stained all of them with Seto’s silver impregnation. These preparations I subjected to minute microscopic study and arrived at the following results.

Individual Views

The oculomotor nucleus in human adult is on the level of colliculus rostralis. The upper end of the nucleus approaches the bottom of 3rd ventriculus in the vicinity of commissura caudalis and the lower end the top of colliculus caudalis, lying adjacent to the inner ventral edge of stratum griseum centrale surrounding aquaeductus mesencephali. The length of the nucleus in sagittal section has been measured variously by Köl liker1) and Krause2) at 5–6 mm. and Obersteiner3) at 6–8 mm., but my measurement resulted in nearly 6 mm. length for all the specimens. The area of the nucleus in transversal section, according to Krause, was about 3 mm²., but I found it larger, i.e., about 5 mm². The oculomotor root fibres, according to Krause, numbered approximately 15,000, which statement I could not verify to satisfaction.

As widely known, the division of the nerve cell groups composing the oculomotor nucleus has been undertaken by Westphal1), Perlia5), Edinger6), Mingazzini7) and others. The inner or the inner dorsal portion consists of a pair of small cell groups, called parasym pathetic nuclei, lying in the stratum griseum centrale on both sides of the median line,
which Jacobsohn\textsuperscript{8}) named sympathetic nuclei and Obersteiner\textsuperscript{3}, the small cellular median nuclei. The outer or the outer ventral portion consists of a pair of large cell groups, generally called the chief nuclei, but the nuclei laterales by Obersteiner\textsuperscript{3}, Edinger\textsuperscript{6} and Tsuchida\textsuperscript{9} and the lateral chief nuclei by Kölliker\textsuperscript{11}. Besides, there is seen the so-called median nucleus between the chief nuclei of both sides and on the ventral side of the nuclei parasymphathici, extending across the median line. This nucleus is not in pair and was called the nucleus centralis by Perlia\textsuperscript{5}, and the nucleus medianus impar by Bernheimer\textsuperscript{10} (Fig. 1).

A. Chief nucleus or Lateral nucleus

The shape of the chief nucleus in transversal section is described as comma-shaped by Monakow\textsuperscript{11} and crescent-shaped by Mingazzini\textsuperscript{7}, but my observation showed its lower part to be triangular with the apex directed ventralward and circumscribing the fasciculus longitudinalis medialis, and its upper part to form an elongated ellipse, independent of the said fasciculus, since the latter gradually parts from the nucleus at higher levels.

This nucleus was thought to be homogenous by Cassirer and Shiff\textsuperscript{12}, Bernheimer\textsuperscript{10}, and Siemerling and Boedeck\textsuperscript{13}, but Edinger\textsuperscript{6}, Obersteiner\textsuperscript{3} and Bach\textsuperscript{14} divided it into the ventral and dorsal parts and Mingazzini\textsuperscript{7} and Kölliker\textsuperscript{11} classified it into four cell groups, dividing the two parts again into the upper and the lower. My observations on the subject is as follows. The classification of the cell groups can be established by the slide series of transversal and sagittal section, and it seems most appropriate to divide the nucleus into the three parts, that is, the ventral, dorsal and caudal parts.

In the rostral levels of the chief nucleus, the dorsal part is on the dorso-lateral side of the nucleus, and shorter and smaller than the ventral part, shaped almost spherical, and better provided with nerve fibre nets than the latter. The dorsal part is demarcated by the surrounding coronal fibres so distinctly, that the division from the ventral part is very clear. The ventral part consists of more numerous but more sporadic nerve cells than the dorsal part, the nerve fibre nets here being more scattered and less curved in their course.

On the contrary, in the lower levels of the chief nucleus, the division between the ventral part and the dorsal part disappears, and the nerve cell group in sagittal section, as shown in Fig. 2, displays a specialized conformation apparently being represented by a separate group as distinguished from the ventral and dorsal parts. From such observations I was led to propose a new division of a caudal part apart from the ventral and dorsal parts.

Now, the nerve cells in the chief nucleus are mostly stellate, but
sometimes pear- and club-shaped, and provided with many stout nerve processes, showing as a whole a form of rugged virile motor nerve cells, which resemble the motor cells in the nucleus n. hypoglossi in man (Sato15) very much. They are easily distinguishable from the round feminine multipolar sensory nerve cells found in the brain trunk. The size of these motor cells is according to Obersteiner3) 50 μ, and by my examination 60 μ in the maximum and 40 μ in the minimum. The nerve fibrils are arranged reticularly in the cell bodies, but in the processes they are spread out at length, without changing in nature. To distinguish the long processes from the short processes is often difficult, but in general the former have lightstaining basal cone in their beginning, which passes into very thin fibre. But this fine fibre becomes strong and more deeply stainable, as soon as it is provided with the myelin. The long process is one per cell in general, but since sometimes two or bifurcated long processes are observed emerging from one cell, the total number of the oculomotor root fibres is accordingly larger than the total number of the nerve cells. The short processes exist in any number from 1 to 6 per cell and they are thicker than the long processes, but stain only weakly. In most cases, they branch out again either after a prolonged course upon emerging from the mother cells, or after a short course. The terminal fibres of the short processes end sometimes unbranched, but sometimes furthermore branched out into minute rami. But I regret to say I could make no further observations on the terminal formation. The cell nucleus of the motor nerve cells is relatively small and located near the center of the cell, and contains a number of deeply stainable granules and one evident nucleolus (Figs. 3 and 4).
Fig. 3. Motor cells in oculomotor chief nucleus in man. Sagittal section. Very complex intranuclear plexus is seen spread out in glia tissue surrounding the nerve cells and their numerous processes. Thick fibres represent motor and sensory fibres, while fine fibres vegetative fibres. Seto's silver impregnation. X 500, reduced to 2/3.

Fig. 4. Ditto. The long process running to the upper right is seen divided into 2 branches before running long. Same staining. X 300, reduced to 1/2.

In the chief nucleus Tsuchida\textsuperscript{9} has found the smaller cells between the large motor nerve cells, similar to those found by Siemerling and Boedeck\textsuperscript{3}, and Bach\textsuperscript{14} in the abducens nucleus, and had his doubt of the motor nature of them. Suzuki\textsuperscript{15} has assumed that these nerve cells represent the centre for the ocular tension and are of extrapyramidal nature, upon experimental research on dogs.

I could ascertain the existence of smaller cells in the chief nucleus, as shown in Fig. 5, which are of size $\frac{1}{3}$--$\frac{1}{1}$ of the motor cells, pear-shaped, somewhat smaller but rounder than the parasympathetic cells of nucleus parasympathicus described hereunder, and are either unipolar or bipolar, with globular nucleus located at or near the center of the cells. The cell nucleus is rather large and the protoplasm is consequently small in quantity, a peculiarity of these cells. From such observations, I conclude that these smaller cells are not motor in nature but are vegetative cells morphologically.

I could also find some nerve cells (Fig. 6), seemingly of sensory nature, at the caudal part of the chief nucleus. They are nearly of the same size as the motor cells, are globular, mainly bipolar and strongly stainable, with one each cell nucleus somewhat smaller than that in motor cells at the center and containing one nucleolus. No description of such cells in the chief nucleus has been known, but the above observations show them to be similar to the sensory nerve cells I found in the nucleus mesencephali n. trigemini\textsuperscript{17}, and I assume they must be similarly of sensory nature. Beattie\textsuperscript{18} found some centripetal nerve fibres seemingly terminating in nucleus mesencephali n. trigemini in the oculomotor root fascicle,
and suggested that they have proprioceptive function. But I believe at least some of these fibres stand in deep relation with the sensory nerve cells I discovered.

In the inner and the ventral parts of fasciculus longitudinalis medialis, the so-called lateral cells by Bernheimer\(^\text{10}\), the "Bucht" cells by Monakow\(^\text{11}\), or the accessory cells by Kölliker\(^\text{1}\), are said to exist. Krause\(^\text{2}\) failed to clarify their nature, but Kölliker\(^\text{1}\), Bernheimer\(^\text{10}\) and Bach\(^\text{14}\) agreed in assuming their motor nature, similar to the nerve cells of the oculomotor nucleus. I also succeeded in observing the existence of not only motor nerve cells similar histologically to those in the chief nucleus at all its levels at the same places, but also of smaller cells of vegetative nature. These nerve cells are spread along the oculomotor root fascicle running through the fasciculus longitudinalis medialis, sometimes forming small groups.

Whether the chief nucleus is divisible into the respective motor centres for the external ocular muscles, has been discussed in the numerous reports by Koehler and Pick\(^\text{19}\), Darkschwitsch\(^\text{20}\), Siemerling\(^\text{18}\), Bach\(^\text{14}\), Panegrossi\(^\text{21}\), Cassirer-Schiff\(^\text{13}\), Majano\(^\text{25}\), Bernheimer\(^\text{10}\), Monakow\(^\text{11}\), Tsuchida\(^\text{9}\) and Breuwer\(^\text{23}\), that of the experimental study on monkeys by Bernheimer in recent days deserving special mention. According to Bernheimer the chief nucleus is areally divided into motor centres, from top downwards, for m. levator palpebrae superioris, m. rectus bulbi superior, m. rectus bulbi nasalis, m. obliquus bulbi inferior and m. rectus bulbi inferior in the order named, the upper two centres innervating
only the muscles on the same side, the next two innervating the muscles on the same as well as on the opposite side, the last one controlling only the muscle on the opposite side, in exclusion of the same side.

However, Siemerling\textsuperscript{13} and Mingazzini\textsuperscript{7} refused the proposed mapping as anatomically unfounded. I also am inclined to look upon the map of Bernheimer as somewhat schematic, considering the complicated intertwining of the nerve fibres in the chief nucleus, ascertained upon the minute scrutiny of the series of my preparations. I would rather have it that the nerve cells innervating the various muscles, instead of being confined to limited special areas, are rather widely spread out, mutually encroaching upon the adjacent central cell groups, and overlapping each other in comparatively wide areas.

B. Nucleus medianus

The median nucleus is in the horizontal section club-shaped according to Obersteiner\textsuperscript{3}, cigar-formed according to Monakow\textsuperscript{11} and almond-shaped according to Mingazzini\textsuperscript{7}, but I would rather describe it as spindle-form. It lies on the median line between the chief nuclei of both sides, and its lateral sides are surrounded by the nerve fibres running parallel in a ventro-dorsal direction. According to Obersteiner, it is not clearly distinguishable from the chief nuclei. Tsuchida\textsuperscript{9} also says that in 20\% of human specimens, the boundary of this nucleus is indistinct. My observations showed that the boundary between the median nucleus and the chief nucleus becomes more accentuated as the upper level is reached, while at the power part of these nuclei, their nerve cells mutually pass over from the one to the other, somewhat blurring out the boundary.

Perlia\textsuperscript{5} and Bernheimer\textsuperscript{10} assert that the nerve cells in the nucleus medianus are histologically similar to the motor cells in the chief nucleus, but in my observations, I found that the former are in the upper part of the median nucleus somewhat different from the latter, though they show in the caudal part more or less similarity to the motor cells in the chief nucleus. Namely, in the median nucleus, multipolar cells diminish gradually as the upper levels are reached, being taken place by many bipolar club- and spindle-shaped cells. The processes of the multipolar cells found here are smaller in number and shorter in length, their protoplasm less stainable than in the cells of the chief nucleus, but the cell nucleus is somewhat bigger (Figs. 7 and 8). The nerve cells in this part are not scattered in arrangement as in the chief nucleus, but are arranged in parallel lines with their long axis oriented ventro-dorsally. Beside the two kinds of cells described above, I found the existence of nerve cells very similar to the vegetative small cells found in the chief nucleus. They are either unipolar or bipolar, a little smaller than the latter, but with somewhat larger cell nucleus. Thus the nucleus medianus contains cells
Fig. 7. A specific bipolar cell (upper) and a small multipolar cell (lower) in the upper part of the oculomotor median nucleus. Horizontal section of human adult mesencephalon. Same staining. X 500, reduced to \( \frac{3}{4} \).

Fig. 8. A small vegetative nerve cell and a motor nerve cell in the oculomotor chief nucleus. Same section. Same staining. X 500, reduced to \( \frac{2}{3} \).

of three types.

Bernheimer\(^{10} \) supposed that this nucleus, together with the parasympathetic nucleus, are connected with the inner ocular muscles, a supposition thrown into doubt by Majano\(^{21} \), Marina\(^{24} \), Edinger\(^{6} \), Brouwer\(^{23} \), Monakow\(^{11} \) and others, who maintained that this nucleus controls the convergence action in connection with the outer ocular muscles. But some neurologists, including Frank\(^{25} \), deem it probable that the convergence control lies with the parasympathetic nuclei. Anyhow, in consideration of the complex cellular structure of this nucleus, it may be surmised that the function of this nucleus is far from a simple nature.

C. Nucleus parasympathicus (Edinger-Westphal’s nucleus)

This pair of nuclei, discovered by Edinger in human embryo and by Westphal in human adult, is located near the median line at the level of the transitional part from ventriculus tertius to aquaeductus mesencephali, more closely conjugated than the chief nuclei of both sides. This nucleus is situated at the upper dorsal side of the chief nucleus, curved in an arc in transversal section, showing a specific histological picture of rough lightness, clearly distinguishable from the surroundings.

The nerve cells are generally small as shown in Fig. 9, being about \( \frac{1}{3} \) in size of the large cells in the chief nucleus. They are either unipolar or bipolar, narrow and long, sometimes elliptical, spindle-form or pear-shaped, one of the poles being round and the other generally more pointed. These oblong cells are arranged rather densely in the direction conforming
Fig. 9. Nerve cells in the oculomotor parasympathetic nucleus in horizontal section of adult human mesencephalon. Note the big size of the cell nucleus. Same staining. X 800, reduced to 2/3.

Fig. 10. Oculomotor root fibres in the same section. Thick fibres show motor fibres and thin ones vegetative fibres. Same staining. X 500, reduced to 1/3.

with the bow-shape of the nucleus, giving of the appearance of a file of fish in shoal.

One of the outstanding characteristics of these nerve cells is the largeness of the cell nucleus. It is generally placed excientrically in the cells, is globular or oval in shape, and the boundary between the surrounding weakly stainable protoplasm is very distinct. The nucleolus is globular, located near the center of the nucleus and strongly stainable.

Since Edinger and Westphal concluded that this nucleus represents a centre for the pupil, Koehler and Pick, Darkschwitch, Bernheimer and Levinsohn proposed that it is a centre for the contraction of pupil, but Juliusburger and Kaplay, Cassirer and Schill, Panegrossi, Majano, Bach, Monakow and Tsuchida refuse to accept the proposal. Recently Ogawa seems also to doubt the validity of the above proposal, from a view point of comparative anatomy. In my observation, as shown in Fig. 10, I found many minute fibres commingling in the oculomotor root, and I have no doubt that the long processes from this nucleus pass into such minute fibres, representing one of the important elements of the oculomotor nerve.

I discovered the existence of a new small cell group (Fig. 11) on the upper dorsal side between the fasciculus longitudinalis medialis and the chief nucleus. These cells histologically agree with the cells in the parasympathetic nucleus, are arranged in group or sometimes sporadically, in a number around 20 in transversal section. I wish to call this nucleus the accessory nucleus of nucleus parasympathicus.
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D. Nucleus anteromedialis

This nucleus (ventral cell group by Mingazzini7)) is located on the ventral side between the fasciculi longitudinales mediales of both sides at the level of the upper part of nucleus medianus, is elliptical in transversal section, with the long axis running ventro-dorsally, and bounded on the outer side by a multitude of fine nerve fibres. This nucleus has been excluded from the oculomotor nucleus by Cassirer-Schiff12), Siemerling-Boedecker13) and Monakow11), but assumed to be the proximate column of nucleus parasympathicus by Edinger13), Obersteiner3) and Greving29). According to Perlia5), Tsuchida9), Panegrossi21), Frank25) and Mingazzini7), it belongs to the oculomotor nucleus, but is independent of the parasympathetic nucleus.

In my study, I observed that this nucleus is analogous to the nucleus parasympathicus in the form and arrangement of the cells. Mingazzini7) failed to elucidate the connection of this nucleus and the parasympathetic nucleus, but I found evidence of the union through a cell-bridge containing these parasympathetic cells in sagittal section. From this fact it may be deduced that these both nuclei are of the same nature. According to a recent study by Frank25) this nucleus also has a close relation with the convergence and regulative action of the ocular muscles.

I also succeeded in discovering medullated thick fibres surrounding the antero-medial nucleus (Fig. 12). These fibres originate in the outer
ventral side of the nucleus, run to the dorsal side thereof to circumscribe its dorsal side in a lemniscus, then run through the inner side of the nucleus toward the ventral side, apparently to mingle with the oculomotor medial root fibres. I wish to call this fibre bundle the fasciculus lemniscularis nuclei anteromedialis.

E. Nucleus dorsocentralis (Nucleus Panegrossi)

This nucleus has been found by Panegrossi in human and by Kölliker\(^1\), Bach\(^{14}\) and Bernheimer\(^{10}\) in animal brains. It is situated at the level of the caudal pat of the chief nucleus on its dorsal side and on the median line. Some questions have been cast upon this belonging to the oculomotor nucleus, but it is said that Panegrossi\(^{21}\), Bernheimer\(^{10}\), Bach\(^{14}\) and Mingazzini\(^7\) have affirmed it by experimental research.

The cells in this nucleus are similar to the large cells in the chief nucleus, though somewhat smaller in size. They are arranged rather in scattered positions, so that the boundary of this nucleus lacks definition. In this nucleus, some smaller vegetative cells, similar to those in the chief and median nuclei, have been observed, though in a small number. From such observations, it could be concluded that this nucleus is also a motor centre for the outer ocular muscles, like the chief and median nuclei.

**Summary**

The oculomotor nucleus comprise the chief nucleus, the median nucleus, the parasympathetic nucleus, the anteromedial nucleus, the dorsocentral nucleus and the accessory nucleus of the parasympathetic nucleus, the last of my own discovery.

The nerve cells in the chief nucleus are represented in their majority by large motor cells provided with many processes and showing virile appearance. The long processes being sometimes double and some-times bifurcated per cell, the total number of the oculomotor root fibres is larger than that of the cells. The short processes apparently end sharply, either unbranched or branched, but their terminal formation is not enough clarified. The cell nucleus is comparatively small and located near the centre of the cells.

The cells of the chief nucleus are partially represented by smaller cells, \(\frac{1}{2}\) to \(\frac{1}{3}\) in size of the large cells, pear-shaped in form, unipolar or bipolar, with a large cell nucleus, presumably being of vegetative nature. Cells of a third type are extremely few in number. Their size is not much different from the large motor cells, but in form, they are globular and unipolar. They are very similar to the sensory nerve cells found in the nucleus mesencephali n. trigemini, and are without doubt of sensory nature.

In the inner and the ventral parts of the fasciculus longitudinalis medialis are found some cells of the same form as the motor cells in the
chief nucleus, with which a small number of small vegetative cells are commingled.

It seems impossible to divide the chief nucleus distinctly into the various motor centres having each fixed boundary for the outer ocular muscles, because they may be thought diffused over comparatively wide parts, overlapping each other to an extent.

The nucleus medianus is inseparable from the chief nucleus at the caudal parts but the boundary between them become more definite as the higher levels are reached. The nerve cells in the basal parts are similar to those in the chief nucleus, but in the upper reaches, more and more bipolar club- or spindle-like cells come into evidence. Also, some smaller cells resembling vegetative nerve cells in the chief nucleus are observable.

The cells in the parasympathetic nucleus are small, about 1/3 of the size of the motor cells in the chief nucleus, are unipolar or bipolar, oblong in shape and arranged rather densely in the direction conforming with the arcuate form of this nucleus. Their protoplasm is only weakly stained, their cell nucleus is oversized, and their long processes are represented by minute fibres. Since such minute fibres are also observable in the oculomotor nerve root, I am inclined to give adherence to the proposal that this nucleus is the centre for the pupillar contraction.

I have discovered a small group of nerve cells strongly resembling those in the parasympathetic nucleus on the rostral side between the fasciculus longitudinalis medialis and the chief nucleus. I propose to call this new nucleus the accessory nucleus of the parasympathetic nucleus.

The anteromedial nucleus is of the same nature as the nucleus parasympathicus, considering the form and the arrangement of the cells. This fact is further evidenced by the union of this nucleus with the parasympathetic nucleus through a cell-bridge containing such cells.

The nerve cells in the nucleus dorsocentralis are somewhat smaller than, but similar to, the motor cells in the chief nucleus. In this nucleus, some smaller vegetative cells, as have been found in the chief and the median nucleus, are observable in a small number. Thus, this nucleus also may be assumed to represent one of the oculomotor centres.

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