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Review Article

Neural Structure and Synaptic Organization of the Thalamic Nuclei

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Abstract

The neural structure of various thalamic nuclei, along with common features, also has significant uniqueness. This concerns, ¬first of all, differences in the organization of relay, associative and non-specific nuclei. Therefore, the neural organization of various groups of thalamic nuclei must be considered separately.

Keywords: neural structure; synaptic organization; thalamic nuclei

Introduction

The neural structure of various thalamic nuclei, along with common features, also has significant uniqueness. This concerns, ¬first of all, differences in the organization of relay, associative and non-specific nuclei. Therefore, the neural organization of various groups of thalamic nuclei must be considered separately. The cellular organization of the various relay nuclei of the thalamus has much in common. Each of the relay nuclei contains ¬several groups of cells. First of all, the relay thalamocortical neurons, which make up the main group of cells in these nuclei. These are large neurons (20-35 μm or more in diameter), with a cross-sectional area exceeding 150 μm 2 [1]. Their dendrites, dividing into 4-10 short dendritic trunks, form a branching pattern equal to 300-400 μm in diameter. The shape of the dendritic field is disc-shaped, the plane of which is usually oriented perpendicular to the course of the afferent ascending -fibers. In Golgi preparations, it is possible to trace the thalamocortical fibers, some of which (about 15%) give off collaterals. The number of relay thalamocortical neurons varies significantly in different parts of the relay nuclei and amounts, for example, to 80-95% . The second main group of cells are interneurons. These are small and large stellate neurons of the Golgi II type. Compared with relay neurons, they are smaller (their bodies are ¬12-20 μm in diameter) and have 2-6 long dendritic ¬trunks. On the dendritic surface there are many pleoform projections ending in one or more thickenings [2]. Such structures differ markedly from the spines of various areas of the brain and are therefore called "projections" or "processes". In total, from 10 to 35% of interneurons are found in the relay thalamic nuclei. Leontovich distinguishes two groups of Golgi II neurons: shaggy and smooth. Smooth cells have fewer and shorter ¬dendrites than shaggy cells ; the size of the axon field, on the contrary, is larger, while the density of the branches of dendrites and their branching points ¬is lower. One of the important characteristics of the interneuron is the presence of complexes of mossy bundles and protrusion-like rosettes on the terminals of dendritic processes, the presence of which is revealed by Golgi staining and is well determined in an electron microscopic study.

Based on the data of light microscopy, two more types of interneurons are determined in the relay nuclei, which differ significantly from those described above and therefore are sometimes ¬distinguished into independent groups. These include reticular-type cells (integrative cells), which make up the main group of cells in the nonspecific ¬nuclei of the thalamus, and are found in no more than 5% of the relay nuclei. These are large (up to 25-50 μm in diameter) cells with long, weakly branching dendrites. The second group consists of small axonless cells, which are also found in addition to the relay nuclei and in nonspecific, in particular, in the intralaminar, nuclei. The body of these cells is very small (3-5 μm in diameter), giving a large number of ¬short, tortuous, dendrite-like processes, at the end of which there is a bundle or a rosette is formed [5]. These elements are similar to the granules of the cerebellum, although the cell body is significantly smaller and the axon is not determined. In the associative nuclei of the thalamus, the neuronal organization ¬resembles the relay nuclei. Here, too, two main types of cells are encountered: relay and interneurons. However, the relay neurons of the associative nuclei are somewhat smaller in diameter (up to 30 μm) than similar cells of the relay nuclei of the thalamus and can be of several types, among which there are spindle-shaped ones. It has been established that they direct axons to the corresponding areas of the cerebral cortex, since they degenerate after the extirpation of these cortical areas. The interneurons are typical Golgi II cells. The ratio between relay cells and interneurons is approximately the same as in the relay nuclei, i.e., 3-3.5 : 1. The nonspecific nuclei of the thalamus are more uniformly constructed than the relay and associative nuclei. The bulk of the neurons of the nonspecific nuclei of the thalamus are similar in shape and dendritic tree to the cells of the reticular formation of the brainstem. These are multipolar

cells, differing ¬in shape and size, characterized by radially extending, rarely branching dendrites. Many of these neurons have axon bifurcations that project in the rostral and caudal directions. Some neurons of the nonspecific nuclei have spines on the body and especially on the long dendrites [7]. In all relay nuclei, specialized structures have been found - glomeruli, which are the receiving apparatus ¬of relay neurons and the place of interaction of impulses coming to them from different sources, i.e. one of the integration levels. The basis of the glomerulus is the dendrite of the relay neuron (one or more) and presynaptic processes of several types: terminals of ascending afferent fibers, corticothalamic fibers and axons of Golgi II cells. Moreover, the terminals of ascending afferent ¬fibers make up no more than 20 % of the endings that organize the glomeruli. Glomeruli are enclosed in capsules of processes or membranes of glial cells. The direction of synaptic transmission in glomeruli is subject to strict laws. For example, the endings of ascending afferent ¬fibers are always presynaptic in relation to the endings of axons of corticothalamic fibers. Each of the relay nuclei has a certain specificity of the structure of the glomeruli. In particular, some sources describe several types ¬of glomeruli depending on what forms the basis of the glomerulus (axon, dendrite or cluster of small branches of axons and dendrites). In addition, the glial capsule of the glomeruli is well expressed, while the glomerulus is free of glial cell processes, which is why the idea was expressed that these are not true glomeruli. However, in all other respects, except for the glial membrane, the described neuronal complexes do not differ from glomeruli and, apparently, can be considered as such. Glomerular synaptic organization is inherent not only to the relay nuclei of the thalamus. Structures similar to glomeruli. Glomeruli located in the nucleus can interact with each other. In any case, such a possibility is assumed ¬in connection with the existence of small axonless elements, in which the rosettes of terminals of different dendrites are part of ¬several glomeruli [11]. Considering that small axonless elements are found both in the relay and nonspecific nuclei of the dorsal thalamus (with rare exceptions), then the unification of glomeruli with the help of such elements may be a characteristic feature of the thalamus.

Synapses of thalamic neurons are classified by their ¬size, vesicle shape, and other features. Several types of contacts are distinguished in relay nuclei. There are large ones, which form the endings of the visual ¬afferent axon, and small ones, formed by the endings of short-axon neurons, as well as the endings of cortical fibers, since the destruction of the visual cortex leads to their degeneration ¬. In non-sensory relay nuclei, two types of contacts are also distinguished. The first ¬type (A) has a symmetrical contact, and the second type (B) is asymmetrical. The second type of contacts makes up the overwhelming majority and is found in two forms: small (Bx) and large (B2). A detailed analysis of the synaptic organization of the association nuclei was carried out in the works of Babmindra. Six types of axon terminals were distinguished: small terminals with large round vesicles (1), with oval ¬vesicles (2), with small round vesicles (3), intermediate terminals with pleoform vesicles (4), large terminals with large round vesicles (5) and with small round vesicles (6). Several types of large and small contacts were described, with large ¬and small synaptic formations localized in different ¬parts of the dendrites [14]. Thus, the synaptoarchitecture of the thalamic nuclei has a complex structure. Along with the structures common to other parts of the brain, in the organization of synaptic contacts formed by ¬axon terminals on the neurons of the thalamus, there are features that apparently underlie the neurophysiological processes that are carried out in this part of the brain.

Distribution of endings of afferent systems in the thalamus

One of the approaches to understanding the functions of the thalamic ¬nuclei is to study the distribution of the endings of various afferent systems in them. However, this approach leads to great difficulties, since the endings of any afferent system are relatively widely distributed in the thalamus, i.e., in addition to the relay, they cover several non-relay nuclei (associative and non-specific). Taking this circumstance into account, Hassler, based on neuroanatomical information obtained from clinical material, presented a picture of the hierarchical organization of various thalamic structures in humans, where the central place is occupied by the endings of various groups of fibers that are part of each afferent system. Not everything is indisputable in Hassler's conclusions; the picture of the organization of the thalamus that he presented is somewhat simplified; however, some provisions, in particular the classification of the functional levels of organization of the thalamic nuclei, deserve to be considered [17]. Hassler distinguishes six levels of organization of the thalamic nuclei by the distribution of six groups of fibers or parts of the thalamus for each sensory system in them, as well as by their connections with the cerebral cortex:

1) relay nuclei, where the switching of afferent ¬influences from the peripheral parts of the sensory systems to the cerebral cortex is carried out. Hassler associates the corresponding sensitivity with the activity of the relay nuclei;
2) the cores of the first level of integration, where the structures ¬responsible for the unconscious perception of a given modality are represented;
3) the nuclei of the second level of integration, represented by structures ¬, the shutdown of which leads to the loss of conscious perception ¬of a given modality;
4) polysensory nuclei, where convergence and interaction of afferent influences of a given sensory modality ¬with other afferent influences takes place;
5) nuclei of non-specific (protopathic) sensitivity related to this sensory system;
6) reticular formations of the thalamus through which the influences from the relay nucleus are transmitted to the corresponding cortical region.

Visual afferent system

Carnivores and primates have several visual afferent systems that run within the optic tract.

The first two of them approach the main relay nucleus of the visual system, which is the dorsal part of the lateral ¬geniculate body. The dorsal part of the nucleus receives up to 2/3 of the fibers of the optic tract and consists of a number of layers, and these layers alternately correspond to the ipsi- and contralateral retinas [19]. In particular, in carnivores, five layers are well expressed: the superficial layer A and deep layers B (C, C2) receive fibers from the contralateral ¬retina, the middle layer Ax and deep C - from the ipsilateral. In primates, there are six layers: three of them are associated with the contralateral retina and the other three - with the ipsilateral. The first two layers are, as a rule, large-celled, and the rest are small-celled.

There are several visual afferent systems. They include the following:

1) The magnocellular geniculostriatal system originates from the rods of the retina. In primates, up to 400 receptors converge on one retinal ganglion cell and one fiber of the optic ¬tract with a diameter of 9-12 μm. These thickest visual fibers end in the magnocellular fields (and from ¬here they project to field 17 of the visual cortex;
2) The parvocellular geniculostriatal system originates from the cones. A limited number of cones (5–20) converge on one ganglion cell and one optic tract fiber with a diameter of 5–8 μm,

which terminate in the parvocellular layers and also project to area 17;

3) pregeniculo-reticular system. The ventral part of the nucleus is transformed in primates into the pregeniculate nucleus. Up to five groups of cells are described, on two of which ¬a certain number of thin fibers of the optic tract end. The nucleus is independent of the cortex, since it does not degenerate after decortication. Fibers from it end in the intralaminar nuclei, superior colliculus, pretectal region, reticular formation of the midbrain ;
4) occipital system of Pu1y. Part of the collaterals of the optic ¬tract terminate in the intergeniculate nucleus of Pu1y. Hassler classifies this afferent system as the first integrative visual projection, since it is connected with field 18 of the visual cortex and therefore carries out simple forms of visual integration;
5) preoccipital system OF PU1Y. Collaterals of the fibers of the visual ¬radiation end in the lateral nucleus of Pu1y. This system is absent in insectivores, but in carnivores and primates it develops progressively. The cortical projection of the lateral nucleus OF PU1Y is field 19 of the visual cortex, and therefore this system, according to Hassler, is responsible for the most complex forms of visual integrative processes [21].

6.3.2 Auditory afferent system

The relay nucleus of the auditory system in the thalamus ¬is the internal geniculate body . The nucleus is divided into the main parvocellular and large cellular parts. In turn, they are divided into ventral and dorsal sections.

In the ventral section, there are predominantly bundle-shaped neurons with a disc-shaped dendritic tree. These neurons, layered on top of each other with disc-shaped dendritic fields, form layers or columns, which gives the ventral section an ordered layered structure. In the dorsal section ¬of the small-celled part, there are large neurons that form a spherical dendritic field [23]. The large-celled section consists of two types of neurons: bundle-shaped and reticular neurons ¬. The auditory pathway approaches the thalamus as part of several (four) bundles:

1) The fibers from the posterior colliculus form the lateral component of the manubrium of the posterior colliculus. These fibers, the average diameter ¬of which in the cat does not exceed 3 μm, approach the parvocellular region and are divided into two components: dorsal and ventral, serving the corresponding parts of the nucleus;
2) The fibers of the lateral lemniscus constitute the medial component ¬of the manubrium of the posterior colliculus, which have passed the quadrigeminal body without synaptic switching. These fibers are directed to the magnocellular part of the nucleus a;
3) Fibers from the reticular formation terminate predominantly ¬in the dorsal region, but they can also be found in the ventral region.

After switching these fibers with the axons of its ¬neurons, the geniculocortical tract is formed, which mainly consists of a portion of the small-celled section with an average fiber diameter of 0.6-3 μm. Some of the fibers (non-myelinated) are the axons of neurons. The cortical projection is fields A I and A II of the auditory cortex, as well as additional fields A III, E p. The main relay nucleus for the somatosensory afferent ¬system is the VR or ventrobasal complex (VBC). This nucleus has two main parts: the external (VBR) and the internal (IRM), or arcuate. A number of authors divide the VBC into the ventral posterior inferior nucleus (VPI), the ventral posterior lateral nucleus (VPL), which is subdivided into lateral (L), medial (VPLm), oral (OPL), and caudal (VPLc) parts, the ventral posterior medial (VPM), and the parvocellular part (PPM1) of the same nucleus [5]. Several afferent systems approach the UVS.

1. The spinocortical tract (medial loop), which adjoins the trigeminal portion, together making up the cuneograciletrigeminal tract. The fibers of the medial ¬loop terminate in the parvocellular part of the n. YBRc, and the trigeminal portion - in URM1 (from where the fibers are directed to field 2 of the somatosensory cortex) and in the posterior part. The medial loop contains fast-conducting fibers from tactile receptors of the skin, receptors of the joint capsules and visceral organs [29].
2. Trigeminal ipsilateral tract, originating from the oral ¬nucleus of the spinal tract of the trigeminal nerve. Fibers after switching to the URM are directed to areas 2 and 3 of the somatosensory cortex.
3. The spinocervicothalamic tract terminates in the YBR, from where the fibers are directed to area 3 of the somatosensory cortex and area 4 of the motor cortex. As part of this tract, thick fibers from tactile receptors, as well as skin pressure receptors and muscle receptors, are directed to the YBR¬. Two spinothalamic tracts are also directed to these nuclei.
4. The neospinal-trigemino-thalamic tract terminates in the small ¬cell nucleus II. UR1, which projects to field 3b of the somatosensory cortex and to the PO (mainly to the PO). The fibers of this tract come from pain, temperature receptors of the skin and receptors that are excited by strong mechanical irritation. As part of this tract (as in the others, but to a lesser extent), fibers from visceral receptors also go to UR1 [26]. The distribution of the endings of the fibers of the spinothalamic tract is significantly less than the territories occupied by the endings of the first three tracts.

The paleospinal-trigemino-thalamic (spinal-trigemino-reticulothalamic) pathway projects to the reticular formation of the brainstem. From the reticular structures, the pathway is directed ¬to the RO and intralaminar nuclei.

1. The taste tract terminates in the parvocellular part of the ventral posteromedial nucleus (UPM1), which occupies the most medial part of the URM. The projection area of fibers from the taste receptors overlaps the area of general sensitivity ¬of the tongue.

All the indicated tracts, but most of all the spinal-trigemino-thalamic ones, send fibers not only to the UVS, but also to the RO and intralaminar nuclei. Tracts switching in the ventral lateral and ventral anterior nuclei of the thalamus

In various sections of the n. Vb, the tracts leading to the motor cortex from the nuclei of the cerebellum and the globus pallidus are switched. According to cyto- and myeloarchitectonics, in carnivores and primates ¬n. Vb has a clear division into dorsal and ventral zones. Afferent tracts approach different parts of n. Vb, and their distribution has a different - rostrocaudal direction [27].

1. In the oral section (n. Yb0), afferents from the internal segment of the globus pallidus are switched, which come here as part of the thalamic bundle of the lenticular loop (bundle of H x Forel). From here they are directed to the field 6a and 6a.
2. The caudal division (n. Vbc) switches afferents from the dentate and, partially, from the intermediate nuclei of the cerebellum, as well as the red nucleus. This region of the nucleus sends fibers to area 4v.
3. The mediocaudal part of n. VL (n. VLM is weakly expressed in carnivores) is a relay for vestibular afferents and muscle spindles. These areas of the nucleus project to field 6a. Stimulation of this area (as well as the vestibulothalamic tract) causes ¬a turn of the head and trunk to the side on which the stimulation was produced.
4. In the rostral parvocellular division of n. UA1, ¬fibers from the external segment of the globus pallidus are switched, which approach the nucleus as part of the dorsal and lateral portions of the lenticular loop. From here they are directed to fields 6aP, 6bp, 4z of the frontal regions of the cerebral cortex, as well as to the insular cortex.

Activation of the entire group of neurons under the influence of the same afferent volley, which guarantees the possibility of accurate signal transmission. And such properties of neurons of the relay nuclei as minimal adaptation to intracellular currents and the absence of significant differences in the thresholds of the membrane of the initial segment and the soma also contribute to the maintenance of linear relationships to the "input-output" characteristic of the relay nucleus.

Sequence of processes occurring in relay nuclei during afferent stimulation

The focal potential arising in the relay nuclei in response to an afferent stimulus has a number of components ¬. The first to arise is a short positive component, followed by a prolonged negative wave with peak potentials. The responses of the i.u. and cuneate nucleus to stimulation of the median (M) and ulnar (U) nerves were recorded [30]. The recording shows that in the cuneate nucleus the response arose 1 ms earlier than the initial positive wave in the thalamus (arrows), which can therefore be interpreted as the initial positive phase of the presynaptic potential created in the thalamus by the discharge of cells of the cuneate nucleus. With slow scanning (b and d), the initial negative wave is followed by a prolonged positive oscillation, which ends with a negative wave with a transition to the next positive one.

Reference:

1. I.P. Pavlov, (2021). Journal of Higher Nervous Activity named after, Vol. 71, No. 2, pp. 164-183
2. Anokhin P.K. Moscow, (1968). Biology and neurophysiology of the conditioned reflex.
3. Batuev A.S. M., (1991). Higher nervous activity.
4. Shapovalov A.: I. St. Petersburg, (1997). Mechanisms of synaptic transmission. Selected works.
5. Novikov V.S., Shustov E.B., Goranchuk V.V. Correction of functional states under extreme influences. – St. Petersburg: Nauka, 1998.
6. Danilova I.N., Krylova A.L. (1999). Physiology of higher nervous activity. - Rostov-on-Don: Phoenix,
7. Ed. B.P.Babmindra. Leningrad. (1986). Morphology of the nervous system. –160 p.
8. Histology, cytology and embryology. Ed. Volkova O.V.,
9. Yu.K.Eletsky. - M., Medicine. 1996. - P. 105-123.
10. L.O.Badalyan. M., Proveshchenie, (1987). Neuropathology. – 303 p.
11. Human Physiology. Edited by V.M.Pokrovsky, G.F.Korotko. Moscow, Medicine. 2001. –P.51-63.
12. Shtanenko, N. I. N. I. Shtanenko, I. L. Kravtsova, I. D. Shlyaga (2012). Morphofunctional features of sensory systems. - Gomel: Gomel State Medical University. - 84 p.
13. Fox, Stuart I. (2016). Human physiology / Stuart I. Fox. — 9th ed. — New York: McGraw -Hill Pres,. — 612 p.
14. Hall, J. E. Guyton and Hall Textbook of medical physiology / J. E. Hall, Arthur C. Guyton. — India: Elsevier, 2016. — 1145 p.
15. (2017). Medical physiology ed. by W. F. Boron, E. L. Boulpaep. — 3rd ed. —Philadelphia: Elsevier, — 1297 p.
16. 16.Shulgovsky V.V. Physiology of higher nervous activity
17. (2003). with the basics of neurobiology: a textbook for students of biological specialty universities. – M.: Academy, – 464 p.
18. I.M. Prishchepa, I.I. Efremenko Prishchepa I.M. (2013). Neurophysiology: a tutorial. – Minsk: Higher. school, –285 p.
19. Dubynin V. A., Kamensky A. A., Sapin M. R., et al. (2003). Regulatory systems of the human body. - M.: Dora,.
20. Kamkin A. G., Kamensky A. A. (2004). Fundamental and clinical physiology. - M.: Publishing center <Academy>.
21. Serkov F.N. and Kazakov V.N. (1980). Neurophysiology of the thalamus, Kyiv, , bibliogr.
22. In arraqu e r-Bordas L. a. O. (1981). Thalamic hemorrhage, Stroke, v. 12, p. 524;
23. Brow n JW Thalamic mechanisms in language, Handb. behavioral neurobiol., ed. by F.A. King, v. 2, p. 215, N. Y, -L., 1979;
24. Dejerine J. a. Roussy G. Le syndrome thalamique, Rev. neurol. (Paris), t. 14, p. 521, 1906;
25. Aleksandrov M.V., Ivanov L.B., Lytaev S.A. (2020). Electroencephalography: manual / ed. M. V. Alexandrova. — 3rd ed., revised. and additional - St. Petersburg: *SpetsLit*,. - 224 p.
26. Galperin S.I. Physiology of man and animals: Textbook for students of universities and pedagogical faculties. – M., 1970. – 655 p.
27. Maksimovich, N. E. N. E. Maksimovich, E. I. Bon, S. M. Zimatkin. Grodno (2020). Rat brain and its response to ischemia: a monograph: GrSMU, - 240 c.
28. Zimatkin S.M. E.I. Bon (2014). Modeling of antenatal exposure to alcohol Novosti *medico-biological sciences*. - № 1. - C. 54 - 55.
29. Zimatkin, S.M. E.I. Bon. - Grodno, GrSMU, (2019). Structure and development of the rat cerebral cortex: a monograph. - 155 c.
30. Bon E.I. S.M. Zimatkin, Vesci NAS Belarusi. (2015). Disruption of the development of neurons of the frontal cortex of the rat brain after exposure to alcohol in the antenatal period. - № 3. - C. 125-128.
31. Bon, E.I. Bon, S.M. Zimatkin. (2016). *Novosti medico-biological sciences*. -. - T. 14. - № 4. - C. 49-54.