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Review Article

Thalamus of the Rat's Brain. Cyto- and Chemoarchitectonics

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Abstract

Objective: Analysis and generalization ofliterature data on the structural and functional organization of the rat thalamus.

Methods: For this research, various literature on the relevant topic was collected and analyzed.

Results: The nuclei of the thalamus can be divided into rostral, lateral and ventral groups, separated by an external medulla lamina, which contains the reticular thalamic nucleus, and an internal medulla lamina containing intralaminar nuclei. The thalamic nuclei are switching, and their classical classification is based on the type of information that is transmitted through a specific nucleus or group of nuclei to the cerebral cortex. There are three main groups of thalamic nuclei: sensory, motor and associative.

Conclusion: The thalamus is a complex of nuclear structures, the neurons of which are very diverse in their neuromediator nature and form numerous afferent and efferent connections with other parts of the brain. The nuclei of the thalamus are involved in a wide range of sensory, behavioral and cognitive reactions of the body and their further study in normal conditions and in experimental pathology provides a fundamental basis for the implementation of results in clinical studies.

Key Words: thalamus; rats; brain

Introduction

Rats are often used as experimental animals, including in research related to the study of the structure and function of the brain. Information about the features of the structure and functioning of different regions of the rat brain creates a fundamental basis for various scientific projects. The thalamus of the rat is located between the hemispheres of the brain and the trunk, and anatomically, the dorsal and ventral parts are distinguished in it. The neurons of the nuclei of the dorsal thalamus form synaptic connections with the cerebral cortex, brainstem and amygdala, and all their afferent and efferent projections pass through the ventral thalamus. Differences in the nuclei of the thalamus are based mainly on cytoarchitectonic, neurotransmitter, and functional features, and their classification is rather complicated [4, 21, 22].

The PURPOSE of this review is to analyze and summarize the literature data on the structure and functions of the rat thalamus for further study in normal and experimental pathology, which will serve as a fundamental basis for clinical research.

General aspects of the organization of the thalamus. The thalamic nuclei can be divided into rostral, lateral, and ventral groups, separated by the outer medullary plate, which contains the reticular thalamic nucleus. Medially and dorsally, the thalamus borders on the third and lateral ventricles of the brain. The internal medullary plate divides the nuclei of the thalamus into dorsal, medial ventral, lateral and caudal groups. In the innermost medullary plate are the intralaminar thalamic nuclei.

Classical functional classification of the thalamic nuclei. The thalamic nuclei are switching, and their classical classification is based on the type of information that is transmitted through a particular nucleus or group of nuclei to the cerebral cortex.

There are three main groups of thalamic nuclei: sensory, motor and associative.

Characteristic of major thalamus nuclei

Sensory nuclei.

Lateral geniculate nuclei.

This complex includes the dorsal lateral geniculate nucleus and the ventral lateral geniculate nucleus separated by the intergeniculate region.

Dorsal lateral geniculate nucleus

contains several types of interneurons, mainly GABAergic with co-expression of NADPH-diaphorase. Also in this nucleus, neurons expressing calretinin, parvalbumin, and calbindin were found. The dorsal lateral geniculate nucleus forms connections with the primary visual cortex (layer IV) [19].

The ventral lateral geniculate nucleus can be considered as a caudodorsal extension of the reticular thalamic nucleus. The nucleus contains enkephalinergic and calretinergic neurons, the expression of substance P is also noted. Afferent fibers reach other nuclei of the thalamus, substantia nigra and deep cerebellar nuclei, and efferent fibers come from neurons of the retina and layer V of the visual cortex.

The neurons of ***the intergeniculate region*** contain neuropeptide Y, substance P, enkephalin, and neurokinin. Afferents come from neurons in the retina, hypothalamus, and brainstem. Efferents reach other thalamic nuclei and the hypothalamus.

The dorsal lateral geniculate nucleus and the lateral portion of the ventral lateral geniculate nucleus transmit visual information to the primary visual cortex. The intergeniculate region is a link between the retina and the hypothalamus and is involved in the regulation of circadian rhythms [9, 11, 24].

Ventral-caudal complex of nuclei.

The ventral-caudal complex of nuclei in rats occupies the ventrolateral region of the thalamus, ventrally and laterally it is limited by the medial loop and the reticular thalamic nucleus, and in the rostral direction it is gradually replaced by the ventrolateral nucleus. The nuclei of the ventrocaudal complex contain neurons expressing GABA, acetylcholine, substance P, calretinin, and calbindin.

Afferent fibers come from the spinal cord, the reticular formation (nociceptive system), the trigeminal nucleus and the raphe nuclei. Efferents go to the somatosensory cortex (layers I, V and VI).

On the nuclei of the ventral-caudal complex, nociceptive, tactile, and kinesthetic sensitivity and impulses coming from vibrissae are switched [3, 13, 26].

Caudal complex of nuclei.

In front of the caudal complex, the lateral nuclei are located, and more medially, the intralaminar ones. The caudal group includes: the ethmoid, scaphoid, and retroethmoid nuclei (the neurons are located at a sufficiently large distance from each other) and the ventral posteriomedial nucleus, formed by a dense accumulation of neuron bodies. Neurons of the caudal nuclei express acetylcholinesterase (most actively in the ventral posteriomedial nucleus) and, to a lesser extent, calbindin, calretinin, and parvalbumin.

Afferent fibers come from the spinal cord, vestibular nuclei and nuclei of the trigeminal nerve. Synaptic connections between the ventral posteriomedial nucleus and the red nuclei are described.

The efferents of the nuclei of the caudal complex reach the sensory cortex (layers VI and I). The main corticothalamic pathway to the caudal nuclei originates from layer V (large pyramidal neurons), and additional efferents that act as signal modulators originate from polymorphic layer VI of the cerebral cortex.

The caudal complex receives motor signals for active movements of rat vibrissae and also provides sensory feedback with them [3].

Ventral posterior nucleus.

The ventral posterior nucleus is composed of a thin sheet of neurons and is usually divided into medial and lateral regions.

In addition to a moderate number of calbindin-positive neurons, the ventral posterior nucleus contains neurons expressing peptides similar to calcitonin.

The ventral posterior nucleus receives afferent inputs from the spinal cord, the nucleus of the trigeminal nerve, and the sphenoid nucleus. Efferent fibers reach the amygdala, striatum and cerebral cortex. Cortical projections mainly form terminals in the granular and agranular areas of the insular cortex [18].

The main function of the ventral posterior nucleus is to transmit information from the peripheral taste analyzer to the cerebral cortex [7].

Medial geniculate nucleus.

The medial geniculate nucleus is formed by a caudal extension of the thalamus and is located ventral to the lateral nucleus complex. The medial geniculate nucleus can be subdivided into medial, ventral, and dorsal subnuclei. The neurons of this complex are small, mainly GABAergic. Their dendritic branches have a spiral structure.

Afferent fibers enter the medial geniculate nucleus from the midbrain colliculum, and efferents reach the amygdala, striatum, globus pallidus, and primary auditory cortex of the temporal lobe (layers I, III, IV, V, and VI) [6, 17].

The medial nucleus transmits acoustic information to the cerebral cortex. In addition, the neurons of this complex provide integration of auditory signals with other sensory modalities, as well as analyze the emotional and mnemonic aspects of perceived sounds and participate in the implementation of the behavioral response to acoustic stimuli [5].

Motor nuclei.

The ventrolateral and ventrorostral nuclei complex is formed by large neurons.

The activity of acetylcholinesterase is somewhat higher in the ventrolateral nucleus; both nuclei contain calbindin- and parvalbumin-positive neurons [12].

This complex receives afferents mainly from the cerebellum and basal ganglia. Efferent fibers go to the motor areas of the cerebral cortex (layers I, II, V) [16].

This nuclear complex plays an important role in the coordination of complex movements [25].

Ventromedial nucleus.

The ventromedial nucleus of the thalamus has an elongated shape, the perikaryons of neurons are located quite densely.

The acetylcholinesterase activity of this nucleus is low; neurons expressing calretinin, calbindin, and parvalbumin are found [12].

Afferent inputs are formed by processes of neurons of the reticular formation, globus pallidus, colliculum, substantia nigra, raphe nuclei, trigeminal nucleus, and cerebellum. Efferents go to the motor cortex (I, III and V layers).

The ventromedial nucleus of the thalamus plays an important role in the integration of motor reactions and coordination of the body's response to pain stimuli [14, 26].

Associative nuclei.

Mediodorsal nucleus.

The mediodorsal thalamic nucleus in rats is usually divided into three regions: medial, central, and lateral. The central region is mainly formed by the perikarya of stellate neurons, while the medial and lateral regions are formed by the bodies of fusiform neurons. Usually dendritic branches do not leave the boundaries of the nucleus [12].

The lateral region contains a large number of neurons synthesizing acetylcholinesterase. Calbindin-positive neurons are mainly located in the lateral and medial regions.

The mediodorsal thalamic nucleus receives afferents from the amygdala, brain stem nuclei, globus pallidus, substantia nigra and forms efferents with the frontal (I, III layers), cingulate cortex and agranular zone of the insular cortex.

The mediodorsal nucleus is involved in the regulation of the body's reactions to stimuli received from the sense of smell, as well as in the implementation of such cognitive functions as attention, learning, and memory [1].

Submedial nucleus.

Submedial nucleus of thalamus is located in the ventral part of the thalamus.

It is formed by neurons expressing parvalbumin and acetylcholinesterase.

Afferent fibers come from the spinal cord, trigeminal nucleus, brain stem, colliculum, and piriform cortex. Efferents terminate in the frontal cortex.

The thalamic submedial nucleus is part of the nociceptive system and is involved in the perception of pain [10, 26, 13].

Rostral nuclei.

The rostral part of the thalamus contains the anterodorsal, anteroventral, and rostramedial nuclei. The anterodorsal nucleus is formed by large hyperchromic neurons, while the other nuclei are small, slightly stained.

Neurons in the rostral nuclei express calbindin, calretinin, and parvalbumin.

The rostral nuclei receive afferents from the hippocampal region, the mammillary nuclei, the raphe nucleus, the brainstem, the reticular nucleus, and the efferents extend to the hippocampus, entorhinal, frontal and occipital cortex.

Rostral nuclei are necessary to provide orientation in space and the formation of spatial memory and learning [1, 2, 23].

Lateral nuclei.

The lateral thalamic complex consists of the posteriolateral and dorsolateral nuclei.

Acetylcholinesterase activity in the posterior lateral nucleus is significantly higher than in the dorsolateral nucleus. In addition, both nuclei contain cabindin- and parvalbumin-positive neurons.

The lateral thalamic complex is formed by afferent connections with the reticular nucleus, retrosplenial (layers V, VI), temporal, parietal and occipital cortex. Efferent fibers go to the entorhinal, parietal and occipital cortex.

The lateral nuclei are involved in the process of spatial learning and memory [1, 24].

Median and intralaminar nuclei.

The median nuclei form a narrow strip in the dorso-ventral direction of the thalamus. The intralaminar nuclei are located in the inner medullary plate.

The complex of the ***median nuclei*** includes the paraventricular, parataenal, intermediodorsal, and rhomboid nuclei, whose neurons express acetylcholinesterase, calretinin, calbindin, parvalbumin, and preproenkephalin.

The median nuclei receive afferents from the spinal cord, reticular formation, hypothalamus, raphe nuclei, globus pallidus, reticular formation, superior colliculum, septal region, amygdala, substantia nigra, and agranular insular cortex. Efferents go to subcortical nuclei, frontal and parietal cortex (layers V, VI) [15].

The intralaminar thalamic nuclei are subdivided into rostral and caudal nuclei. The neurons in this complex are very densely packed and express calbindin, parvalbumin, calretinin, and enkephalin.

Afferent fibers go from the reticular formation, pons, brainstem, cerebellum, hypothalamus, nucleus reticularis, and cingulate cortex.

Efferent fibers reach the striatum, hypothalamus, frontal and parietal cortex (layers V, VI) [6, 15].

The functions of the median and intralaminar nuclei are to regulate sexual behavior and coordinate the body's response to external stimuli of various modalities [8].

Reticular nucleus.

The reticular nucleus is located between the dorsal thalamus and the cerebral hemispheres, its neurons express GABA, calretinin and parvalbumin.

Unlike other thalamic nuclei, the reticular nucleus does not form synaptic connections with the cerebral cortex, but forms terminals (afferent and efferent) with other nuclei of the dorsal thalamus.

The reticular nucleus plays the role of a selector, selecting information that should enter the cortex, and, in addition, synchronizes the activity of other thalamic nuclei [20].

Thus, the thalamus is a complex of nuclear structures, its neurons are very diverse in their neurotransmitter nature and form numerous afferent and efferent connections with other parts of the brain. The nuclei of the thalamus are involved in a wide range of sensory, behavioral and cognitive reactions of the body, and their further study in normal and experimental pathology provides a fundamental basis for the implementation of the results in clinical research.

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