

The Thalamus: A Review of its Functional Anatomy

Author:

Rengin Kosif, Assoc. Prof.
Abant Izzet Baysal University,
Faculty of Medicine, Department
of Anatomy
BOLU - TURKEY

Correspondence Address:

Rengin Kosif, Assoc. Prof.
Abant Izzet Baysal University,
Faculty of Medicine, Department
of Anatomy
BOLU - TURKEY
Tel: (0374) 2534656-3043
Fax: (0374) 2534559
E-mail: rengink@yahoo.com

Abstract

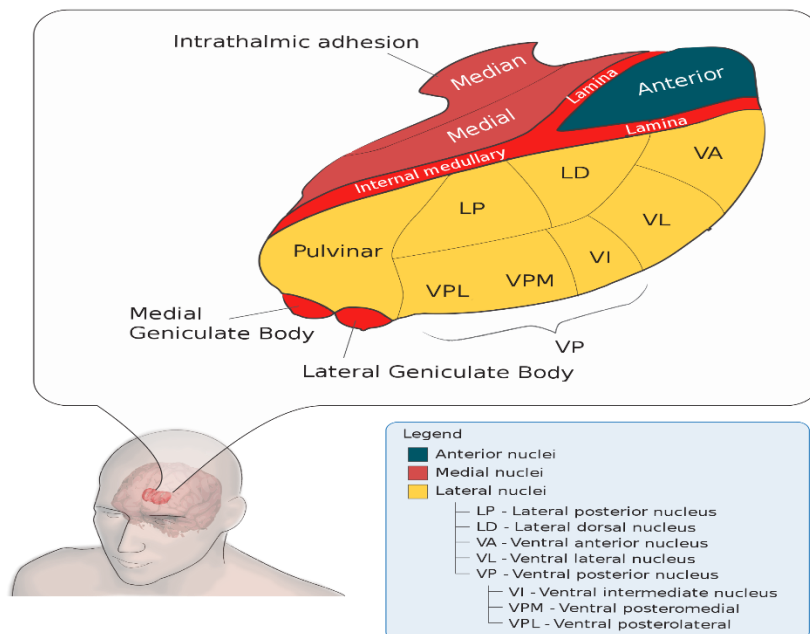
The diencephalon can be divided into four areas, which are interposed between the brain stem and cerebral hemispheres. The four subdivisions include the hypothalamus to be discussed in a separate lecture, the ventral thalamus containing the subthalamic nucleus already discussed, the epithalamus which is made up mostly of the pineal body, and the dorsal thalamus (henceforth referred to as the thalamus). Anatomically, the dorsal thalamus is subdivided into 50-60 nuclear groups. The focus of this review is its functional anatomy. In the spinal cord and brain stem portions of the course, certain relay nuclei of the thalamus transfer information from sub-cortical structures to the cerebral cortex. By virtue of these relay functions that encompass the major senses and motor systems, the thalamus is often referred to as the gateway to the cortex. The thalamus has numerous connections to other areas of the brain as well, and these are thought to be important in the integration of cerebral, cerebellar, and brainstem activity. Branches of the posterior cerebral artery supply much of the thalamus. Occlusion of these small branches results in a number of symptoms characteristic of the thalamic syndrome.

Keywords: Thalamus, nuclei, functional anatomy

The Thalamic Nuclei: A Review of its Functional Anatomy

The human thalamus is a nuclear complex located in the diencephalon and comprising of four parts (the hypothalamus, the epithalamus, the ventral thalamus, and the dorsal thalamus). The dorsal thalamus is referred to as the thalamus and largest structure of the diencephalon. The thalamus is a relay centre subserving both sensory and motor mechanisms. Thalamic nuclei (50-60 nuclei) project to one or a few well-defined cortical areas (1). There are four thalamic vascular syndromes corresponding to the vascular territories of

the thalamus supplied by four arteries: tuberothalamic artery, paramedian artery, inferolateral artery, and posterior choroidal artery. Anatomically, the thalamus can be subdivided in nuclear groups with respect to the internal medullary lamina, the anterior, medial, lateral, intralaminar, and posterior nuclei, and to the external medullary lamina, the reticular nucleus (RN). The thalamic nuclei can be grouped into six functional classes: the RN, the specific sensory nuclei, the effector nuclei, the limbic nuclei, the intralaminar nuclei, and the associative nuclei (2).



1. Anterior nuclear complex: AD Anterodorsal nucleus, AM Anteromedial nucleus, AV Anteroventral nucleus, LD Laterodorsal nucleus.

- 2. Medial–midline group:** MDmc Mediodorsal magnocellular nucleus, MDpc Mediodorsal parvocellular nucleus, Pt Paratenial nucleus, PV Paraventricular nucleus, Re Nucleus reuniens.
- 3. Lateral group:** LP Lateral posterior nucleus (lateral dorsal group), VA Ventral anterior nucleus (lateral ventral group), VL Ventral lateral nucleus (lateral ventral group), VM Ventral medial nucleus (lateral ventral group), VP Ventral posterior nucleus (lateral ventral group), VPL Ventral posterolateral nucleus, VPM Ventral posteromedial nucleus, VPpo Ventral posterior nucleus, VPI Ventral posterior inferior nucleus.
- 4. Intralaminar group:** CL Central lateral nucleus (intralaminar group – anterior/rostral), CM Centromedian nucleus (intralaminar group – posterior/caudal), PCn Paracentral nucleus (intralaminar group – anterior/rostral), Pf Parafascicular nucleus (intralaminar group – posterior/caudal)
- 5. Posterior group:** Pul Pulvinar complex, PM Pulvinar inferior/medial nucleus
- 6. Metathalamus:** LGN Lateral geniculate nucleus, MGN Medial geniculate nucleus, RN Reticular nucleus.

The thalamus is an important relay center subserving sensory and motor mechanisms, arousal, cortical synchrony, emotion, cognition, and memory. However, not only thalamic neurons are relays of information, but also they have a role in controlling executive networks and in regulating complex behaviors, such as behavioral flexibility and reward-directed behavior (2).

The thalamic anterior nuclei: The nuclear ensemble is encapsulated by myelinated fibers that appear to be an anterior extension of the intralaminar system. Afferent connections come largely from the hippocampus and subiculum, projecting directly onto the anterior

complex via the fornix and indirectly via the mammillary body and the mammillothalamic tract. Brainstem fibers from the dorsal raphe and pedunculopontine nuclei also reach the anterior nuclei. Efferent fibers project to all portions of the cingulate gyrus and to other parts of the limbic cortex and orbitofrontal area (3).

The anterior nucleus of the thalamus (ANT) is a key component of the hippocampal system for episodic memory. The ANT consist of 3 subnuclei with distinct connectivity with the subicular cortex, retrosplenial cortex, and mammillary bodies. Via its connections with the anterior cingulate and

orbitomedial prefrontal cortex, the ANT may also contribute to reciprocal hippocampal-prefrontal interactions involved in emotional and executive functions (4).

Clinical and experimental evidence indicate that damage of the ANT or its inputs from the mammillary bodies are primarily responsible for the episodic memory deficit observed in Wernicke-Korsakoff syndrome and thalamic stroke. Experimental models also indicate that the ANT may have a role in the propagation of seizure activity both in absence and in focal seizures. Because of its central connectivity and possible role in propagation of seizure activity, the ANT has become an attractive target for deep brain stimulation (DBS) for treatment of medically refractory epilepsy (4).

The thalamic midline and intralaminar nuclei, long thought to be a non-specific arousing system in the brain, have been shown to be involved in separate and specific brain functions, such as specific cognitive, sensory and motor functions. Fundamental to the participation of the midline and intralaminar nuclei in such diverse functions seems to be a role in awareness (5). Because of their strong brainstem inputs, the intralaminar and midline nuclei are considered as part of the ascending

reticular activating system (ARAS), the rostral continuation of the reticular formation (6). Intralaminar/midline-induced cortical activation would lead to greater vigilance, necessary for awareness of incoming information. It is important to stress that the midline and intralaminar nuclei do not 'produce' awareness, but rather provide the necessary arousal of cortical and subcortical regions supporting information processing that is correlated with awareness (7). A role in the awareness of tactile and nociceptive information has been described as well for the midline and intralaminar nuclei. This derives from the anatomical evidence that the above nuclei receive nociceptive input from the spinothalamic and spinoreticulothalamic projections (8). The intralaminar thalamic nuclei are a part of the thalamus, the relay station for visual, somatosensory, and auditory information to the cortex. These nuclei are also involved in attention and arousal (9).

The thalamic lateral nuclei: The VPL and VPM nuclei are part of the somatosensory system. The VPL relays medial lemniscal and spinothalamic connections to the cerebral cortex. The VPM receives trigeminothalamic input and relays to the inferior portion of the postcentral gyrus. The VL receives input from the cerebellum, mainly from the

dentate nucleus. There is a small input from the basal ganglia to the rostral part of the VL, as well. The VL projects to the primary motor area, area 4, of the precentral gyrus and also has a smaller projection to premotor areas. The VL is thus involved in motor feedback from the cerebellum and basal ganglia to the cerebral cortex. The VA nucleus receives most of its input from the basal ganglia, especially the medial globus pallidus and substantia nigra, parts reticulata. This projects to premotor cortex including the supplementary motor area of the frontal lobes and is involved in planning and initiating movements (10). VL projections target caudal motor areas (primary, supplementary, and caudal premotor areas), whereas VA projections target more rostral premotor areas (including cingulate and presupplementary motor areas) (11). LP cells required visual input. It was concluded that the LP may pass on to the hippocampal formation directional information that is not merely a reflection of current sensory input. As such, the LP may serve an important integrative function for limbic spatial learning systems (12). The VPI rather than the other nuclei with long latency responses is likely to be the thalamic relay in the vestibulo-cortical path. Projection of VPI neurons to the primary vestibular cortex

was demonstrated by antidromic stimulation. The close topographical relationship between vestibular and somatic areas in the cortex is paralleled in the thalamus, the VPI being closely related to VPL and VPM nuclei (13).

The thalamic posterior nuclei: The pulvinar is the largest association nuclei, occupying the posterior part of the dorsal tier of the thalamus. This receives afferent projections from the superior colliculus as well as from the association cortex. It projects to secondary visual areas and to association areas in the parietotemporal region. This contributes to visual perception and eye movements, probably relating to attention to these stimuli (10).

The posterior nuclei were complicated and varied considerably among neurons: although almost all contained a single elliptical region near the reticulothalamic border, in most cases, they consisted of additional discontinuous regions or relatively diffuse regions throughout the thickness of the thalamic reticular nucleus. Our results suggest two sources of reticular inputs to the posterior nucleus neurons: one that is relatively topographic from regions near the reticulothalamic border and one that is relatively diffuse and convergent from most or all of the thickness of the thalamic reticular nucleus. We propose that the

more topographic reticular input is the basis of local inhibition seen in posterior nucleus neurons and that the more diffuse and convergent input may represent circuitry through which the ventral posterior lateral and posterior nuclei interact (14).

The pulvinar is the only nucleus of this group to identify. This nucleus receives inputs from many diverse areas of the major sensory systems and projects to the all of the association areas of cortex in the parietal, occipital and temporal lobes. One of the primary outputs of pulvinar is to the secondary visual areas (18 and 19). There is evidence that this secondary pathway conveys information only about stimulus position and is not involved in pattern recognition. For our purposes you should think of the pulvinar as an area, which can direct your attention to a new stimulus like a flash of light or a sound (15).

Posterior thalamus seems to be fundamentally involved in our control of upright body posture. Higher pressure, swelling, and other secondary pathologic processes associated with posterior thalamic hemorrhage (vs thalamic infarction) may provoke contraversive pushing in combination with additional neurologic symptoms (Pusher Syndrome) (16). Cells in the posterior thalamus

project to both amygdala and temporal cortex in the rat (17).

The thalamic metathalamic nuclei: Metathalamus is the part of the diencephalon inferior to the caudal end of the dorsal thalamus, comprising the lateral and medial geniculate bodies. The lateral geniculate nucleus is visual, the medial geniculate nucleus is auditory. The medial geniculate nucleus receives ascending GABAergic afferents from the inferior colliculus, the lateral geniculate receives such afferents from the pretectum, there are GABAergic afferents from the zona incerta to higher order thalamic relays and the globus pallidus and substantia nigra and zona incerta send GABAergic axons to the ventral anterior and the center median nucleus (18). The thalamic reticular nucleus (TRN) controls the internal attentional searchlight that simultaneously highlights all the neural circuits called on by the object of attention. In other words, he submitted that during either perception, or the preparation and execution of any cognitive and/or motor task, the TRN sets all the corresponding thalamocortical circuits in motion. Over the last two decades, behavioural, electrophysiological, anatomical and neurochemical findings have been accumulating, supporting the complex nature of the TRN and raising

questions about the validity of this speculative hypothesis. Indeed, our knowledge of the actual functioning of the TRN is still sprinkled with unresolved questions. Therefore, the time has come to join forces and discuss some recent cellular and network findings concerning this diencephalic GABAergic structure, which plays important roles during various states of consciousness. On the whole, the present critical survey emphasizes the TRN's complexity, and provides arguments combining anatomy, physiology and cognitive psychology (19). The reticular thalamic nucleus receives afferents from the brain stem reticular formation as well as from the cerebral cortex and thalamus. This makes a strongly inhibitory input to thalamic nuclei. This nucleus may be important in sleep wake cycles and maybe an important regulator of signals relaying through the thalamus (10).

Multiple cortical areas receive afferents from a single thalamic nucleus and send back information to different thalamic nuclei. The corticofugal projection provides positive feedback to the "correct" input, while at the same time suppressing irrelevant information. Topographical organization of the

thalamic afferents and efferents is contralateral, and the lateralisation of the thalamic functions affects both sensory and motoric aspects. Symptoms of lesions located in the thalamus are closely related to the function of the areas involved. An infarction or haemorrhage thalamic lesion can develop somatosensory disturbances and/or central pain in the opposite hemibody, analgesic or purely algesic thalamic syndrome characterised by contralateral anaesthesia (or hypaesthesia), contralateral weakness, ataxia and, often, persistent spontaneous pain (1). A case is presented of an adult male with a thalamic infarct resulting in a paramedian thalamic syndrome, consisting of hypersomnolence, confabulatory anterograde amnesia (including reduplicative paramnesia), vertical gaze deficits, and hypophonic speech (20).

It is now appreciated that the thalamus plays critical roles in the most fundamental aspects of brain function, including: (i) integration, processing, and cognition of sensory information; (ii) regulation of consciousness, including arousal, awareness, and attention; and (iii) modulation of the pyramidal and extrapyramidal motor systems (3).

REFERENCES

1. Herrero MT, Barcia C, Navarro JM. Functional Anatomy Of Thalamus And Basal Ganglia. *Childs Nerv Syst.* 2002; 18(8):386-404.
2. Herrero MT, Insausti R, Estrada C. Thalamus: Anatomy. *Brain Mapping: An Encyclopedic Reference*, 2015, pg:229– 242, Volume2:Anatomy and Physiology, Systems. <http://dx.doi.org/10.1016/B978-0-12-397025-1.00216-5>.
3. Katz DM, Chandar K. Thalamus. *Encyclopedia of the Neurological Sciences (Second Edition)*. 2014; pg: 425– 430.
4. Child ND, Benarroch EE. Anterior Nucleus Of The Thalamus: Functional Organization And Clinical Implications. *Neurology.* 2013; 81(21):1869-76.
5. Van der Werf YD, Witter MP, Groenewegen HJ. The Intralaminar And Midline Nuclei Of The Thalamus. Anatomical And Functional Evidence For Participation in Processes Of Arousal And Awareness. *Brain Research Reviews.* 2002; 39(2–3):107–140.
6. Steriade M, Glenn LL. Neocortical And Caudate Projections Of Intralaminar Thalamic Neurons And Their Synaptic Excitation From Midbrain Reticular Core. *J. Neurophysiol.* 1982; 48 pg:352–371.
7. Steriade M. Thalamic Substrates Of Disturbances In States Of Vigilance And Consciousness in Humans. Steriade M, Jones EG, McCormick DA (Eds.), *Thalamus, Experimental and Clinical Aspects*, Vol. II, Elsevier, Amsterdam. 1997; pg:721–742.
8. Sturm W, De Simone A, Krause BJ, Specht K, Hesselmann V, Radermacher I, Herzog H, Tellmann L, Müller-Gärtner HW, Willmes K. Functional Anatomy Of Intrinsic Alertness: Evidence For A Fronto-Parietal-Thalamic-Brainstem Network In The Right Hemisphere. *Neuropsychologia*, 1999; pg:797– 805.
9. Kinomura S, Larsson J, Gulyás B, Roland PE. Activation by Attention Of The Human Reticular Formation And Thalamic Intralaminar Nuclei. *Science*, 1996; 271:512 – 515.
10. Swenson RS. Review of Clinical and Functional Neuroscience. Chapter 10 , Thalamic Organization. http://www.dartmouth.edu/%7Eerswenson/NeuroSci/chapter_10.html.
11. McFarland NR, Haber SN. Thalamic Relay Nuclei of the Basal Ganglia Form Both Reciprocal and Nonreciprocal Cortical Connections, Linking Multiple Frontal Cortical Areas.

The Journal of Neuroscience. 2002; 22(18):8117-8132.

12. Mizumori SJ, Williams JD. Directionally selective mnemonic properties of neurons in the lateral dorsal nucleus of the thalamus of rats. The Journal of Neuroscience. 1993; 13(9): 4015-4028.

13. Deecke L, Schwarz DWF, Fredrickson JM. Nucleus ventroposterior inferior (VPI) as the vestibular thalamic relay in the rhesus monkey I. field potential investigation. Experimental Brain Research. 1974; 20(1):88–100.

14. Lam YW, Sherman SM. Different topography of the reticulothalamic inputs to first- and higher-order somatosensory thalamic relays revealed using photostimulation. J Neurophysiol. 2007; 98(5):2903-9.

15. <http://www.neuroanatomy.wisc.edu/coursebook/thalamus.pdf>.

16. Karnath HO, Johannsen L, Broetz D, Küker W. Posterior Thalamic Hemorrhage Induces “Pusher Syndrome”. Neurology. 2005; 64(6):1014-1019.

17. Doron NN, Ledoux JE. Cells in the posterior thalamus project to both amygdala and temporal cortex: A quantitative retrograde double-labeling study in the rat. Journal of Comparative Neurology. 2000; 425(2):257–274.

18. Sherman SM, Guillery RW. Exploring the Thalamus and Its Role in Cortical Function, Second edition. 2nd edition. Chapter I. Cambridge, MA USA.
https://mitpress.mit.edu/sites/default/files/titles/content/9780262513449_sch_0001.pdf.

19. Pinault D. The Thalamic Reticular Nucleus: Structure, Function And Concept. Brain Research Reviews. 2004; 46(1): 1–31.

20. Spinella M. Hypersexuality and Dysexecutive Syndrome After A Thalamic Infarct. Int J Neurosci. 2004; 114(12):1581-90.