Thalamic nuclei

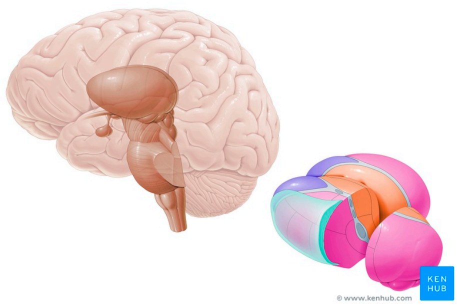
Introduction

For the successful completion of any task, some sort of recognition, identification and organisation is needed. Imagine what would happen if employees in a team would just start working aimlessly, without having some sort of direction or goal in mind. For a group to be focused on its goal, it needs a manager who can identify and organise all the extraneous information sent to the team. The brain is no different. This intricate anatomical structure needs a manager to filter, relay and group incoming information accordingly in order to perform its job properly. This little saviour is the thalamus. This article will briefly discuss the thalamus as a whole, before entering into some details about the various thalamic nuclei.

Thalamus

Relations

The **thalamus** is an egg shaped mass of grey matter which forms a major part of the **diencephalon**, the latter being the posterior part of the prosencephalon or forebrain. There are two thalami in total, one situated on each side of the **third ventricle** (a cerebrospinal fluid filled cavity). They are connected by a band of grey matter called the **interthalamic connection** or adhesion.



Thalamic Nuclei

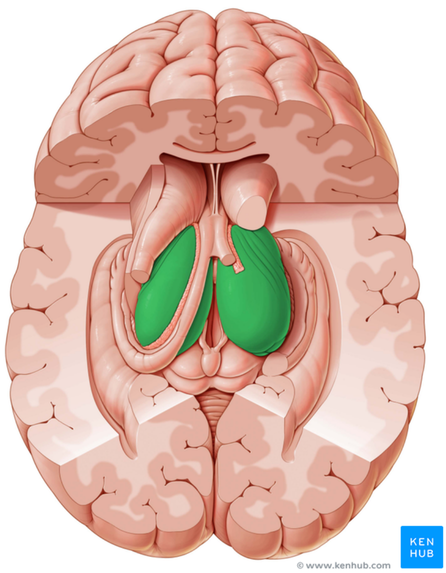
Each thalamus has several well defined borders:

- **Anteriorly** – posterior boundary of the **interventricular foramen**, a channel allowing the movement of cerebrospinal fluid from the lateral to the third ventricles
- **Posteriorly** – an expansion called the **pulvinar**
- **Inferiorly** – the **tegmentum** or floor of the midbrain
- **Medially** – lateral wall of the **third ventricle**

Functions

The thalamus is considered a major sensory and motor **relay station** for the cerebral cortex, brain stem, hypothalamus and basal ganglia. Think of this structure as a processing centre in the middle of the brain. All the information coming into the brain is first **sorted**, **integrated**, and **analysed** by the thalami before it is sent further on. Imagine this structure being a warehouse where packages are stored and sorted before delivery to their respective customers. The thalamus sorts out and interprets, to a certain extent, incoming sensory and motor information. It also has an ability to **control the information** projected to and from the cerebral cortex, thus influencing levels of **consciousness** and **alertness**. In addition, it receives feedback and connections from the cortex itself and other structures, being involved even in **behavioural arousals** and **sleep-wake cycles**. The feedback from the cortex is so extensive that corticothalamic projections outnumber thalamocortical ones. In other words, this warehouse does not just deliver packages, but it listens and communicates with the customers in order to provide the best service possible.

Organisation



Thalamus - cranial view

The thalamus is capable of carrying out these functions due to its complex and intricate **relaying networks** or tracts. These networks travel to and from structures called **nuclei**, which are special areas within the thalamus where neuronal cell bodies are packed together very densely. If you examine horizontal sections of these nuclei, they resemble eggs made up of grey matter. The nuclei are not randomly dispersed throughout the thalamus, but rather located in well defined parts - **anterior**, **medial** and **lateral** parts. These parts are formed by a vertical sheet of white matter, called the **internal medullary lamina**, which splits the thalamus into three main areas. Luckily, it is quite easy for you to picture the position of the parts due to the resemblance of the lamina to the letter Y. From an anterosuperior perspective, the anterior part lies between the limbs of the Y, while the medial and lateral parts lie on the sides of the stem of the Y. If we go back to our analogy, the warehouse representing the thalamus is not just a big open space. In fact, it is quite the opposite as it has several sections, each one dealing with different aspects of the same package before it is sent to the next step in the chain.

Generally, the thalamic nuclei are **reciprocally connected to the cerebral cortex**, permitting subcortical neuronal activity to influence the cortex. The cortex, in turn, sends input back to the thalamus. **Afferent thalamic networks** usually terminate in layer IV of the cortex. **Corticothalamic fibers** reciprocating signals back to the thalamus arise from layer V and VI of the cortex. Each of the three parts of the thalamus has discrete nuclei, which are explained in the following sections. As the connections of these nuclei are described, you will see that basically there are three types of nuclei:

- **Relay nuclei**, which receive information (eg visual, acoustic, primary somatosensory input) that is very specific and well-defined, and project this information to very specific, functionally discrete cortical areas.

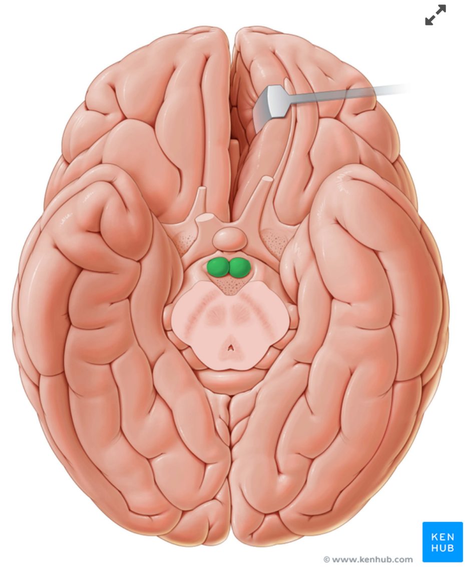
- **Association nuclei**, which receive most of their information from the cerebral cortex itself, and then feedback to "association areas" in the cortex to regulate the integration and interpretation of the sensory information.
- **Nonspecific nuclei**, such as the intralaminar nuclei, which show broad projections and appear to be involved in alerting function, among others.

Anterior Part

This part contains the **anterior thalamic nuclei**. There are three subdivisions of the anterior part of the thalamus: **anteroventral**, **anteromedial** and **anterodorsal nuclei**.

These nuclei receive information from the so-called **limbic system** of the brain, giving them important functions and influence upon **emotional states** and **memory**. This system is a collection of structures derived from the main parts of the brain like the telencephalon, diencephalon and mesencephalon. The specific **communications of the anterior thalamic** nuclei are as follows:

- Anteroventral nuclei
  - Ipsilateral medial mammillary nucleus (**afferent**)
- Anteromedial
  - Ipsilateral medial mammillary nucleus (**afferent**)
- Anterodorsal
  - Lateral mammillary nucleus (**afferent**)
- Overall anterior part
  - Anterior limbic area (**efferent**)
  - Cingulate gyrus (**efferent**)
  - Parahippocampal gyrus (**efferent**)
  - Dorsolateral prefrontal and posterior areas of neocortex (**afferent**)



Mammillary body - caudal view

Therefore, this group of nuclei has important functions and influence upon **emotional states**, such as attention and alertness and memory acquisition.

Middle Part

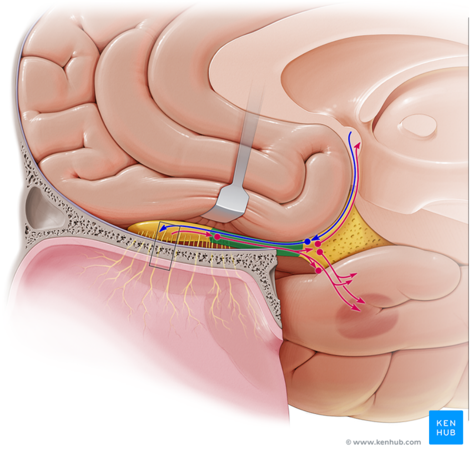
The middle part of the thalamus has one component, called **dorsomedial nucleus**. Its borders include **internal medullary lamina** and **intralaminar nuclei** laterally and the **midline nuclei** medially. The dorsomedial nucleus is subdivided into two parts: **anteromedial magnocellular** and **posterolateral parvocellular**.

The **anteromedial magnocellular part** communicates with several regions of the brain. Some fibers are purely a one way communication (afferent/efferent), while others are two way (reciprocal), as shown below:

- Cortical and subcortical areas for olfactory inputs (**afferent**)
- Posterior olfactory areas of prefrontal cortex (**efferent**)
- Ventromedial cingulate gyrus (**reciprocal**)
- Inferior parietal cortex (**reciprocal**)

Olfactory tract - medial view

- Anterior insula (**reciprocal**)
- Mediobasal amygdaloid nucleus (**afferent**)
- Lateral nuclei (**afferent**)



The **posterolateral parvocellular part** has mostly reciprocal connections with the **prefrontal cortex**, **anterior cingulate gyrus** and **supplementary motor area**.

Through all these connections, the middle part is responsible for **integrating** sensory, motor, visceral and olfactory information and subsequently relating it to the individual's **emotional state**. Its overall functions are similar to those of the prefrontal cortex.

Lateral Part

This nuclei complex is the **largest division** and lies laterally to the internal medullary lamina. Generally, they are divided into dorsal and ventral tiers.

Dorsal Group of Nuclei

This group includes three nuclei subgroups: **lateral dorsal nucleus**, **lateral posterior nucleus** and **pulvinar**. The dorsal group of nuclei communicate with several regions of the brain via afferent fibers. It is also connected with several other areas but the exact nature of these communications is unknown.

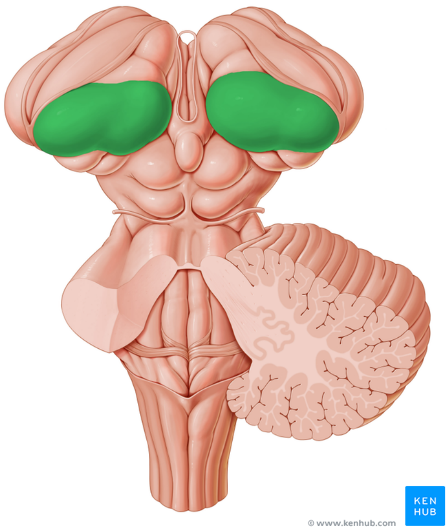
The **lateral dorsal** is the most anterior of the dorsal group of nuclei. Its anterior pole lies in the splitting of the internal medullary lamina and has the following **connections**:

- Pretectum (**afferent**)
- Superior colliculus (**afferent**)
- Cingulate, parahippocampal cortices, parietal cortex, presubiculum (**unknown**)

The **lateral posterior nucleus** lies dorsally to the ventral posterior nucleus and its **communications** include:

- Superior colliculus (**afferent**)
- Superior parietal lobe (**reciprocal**)
- Inferior parietal, cingulate, medial parahippocampal cortex (**unknown**)

The **pulvinar** corresponds to the posterior expansion of the thalamus.



Pulvinar of thalamus - dorsal view

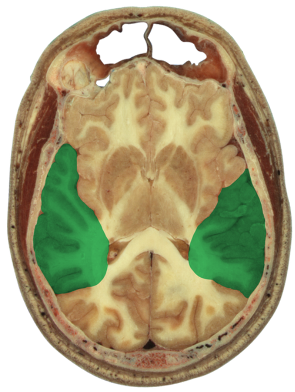
Its subdivisions include the **medial**, **lateral** and **inferior pulvinar nuclei**, which **communicate** as below:

- Medial Nuclei
  - Superior colliculus (**afferent**)
  - Parietotemporal complex (**efferent**)
  - Inferior parietal cortex (**efferent**)
  - Posterior cingulate gyrus (**efferent**)
  - Temporal lobe (**efferent**)
- Lateral Nuclei
  - Superior colliculus (**afferent**)
  - Visual areas in occipital and posterior temporal lobes (**efferent**)
  - Occipital cortex (**efferent**)
  - Temporal association cortex (**efferent**)
  - Parietal cortex (**efferent**)
  - Rostromedial prefrontal cortex (**efferent**)
- Inferior Nuclei
  - Superior colliculus (**afferent**)
  - Retina (**afferent**)
  - Visual areas in posterior temporal lobes (**efferent**)
  - Striate and extrastriate cortex in occipital lobe (**efferent**)

The exact functions of the pulvinar are unknown, but from their connections you can appreciate their

Temporal lobe - cross-sectional view

complexity. It seems to be involved in **vision** due its visually responsive cells, but also in modulating **perception**, **cognition** and **memory** from its interaction with the temporal lobe. There is a possibility the pulvinar might be involved in the **sensation** and **modulation of pain** through its poorly understood association with the anterior (oral) pulvinar, suprageniculate limitans nucleus and posterior nuclei.



Ventral Group of Nuclei

The ventral group also consists of three subgroups: **ventral anterior**, **ventral lateral** and **ventral posterior nuclei**.

Ventral Anterior Nucleus

The **ventral anterior nucleus** lies on the anterior pole of the ventral group of nuclei. It is enclosed by the reticular nucleus anteriorly, ventral lateral nucleus posteriorly and internal and external medullary laminae. It consists of a **principal part** and a **magnocellar part**. This nucleus is located on the path between the corpus striatum and the motor areas of the premotor cortex, relaying information with both. Its **connections** are outlined below:

- Principal part
  - Globus pallidus (**afferent**)
  - Area 6 of premotor cortex (**afferent**)
- Magnocellar part
  - Substantia nigra (**afferent**)
  - Area 8 of premotor cortex (**afferent**)
- Overall ventral anterior nucleus
  - Intralaminar thalamic nuclei (**efferent**)
  - Frontal lobe (**efferent**)
  - Anterior parietal complex (**efferent**)

Through these communications, the ventral anterior nucleus influences the activities of the motor cortex itself. Therefore, it is involved in **planning** and **initiating movements**. It is also involved in transmitting the cortical **"recruiting response"**.

Ventral Lateral Nucleus

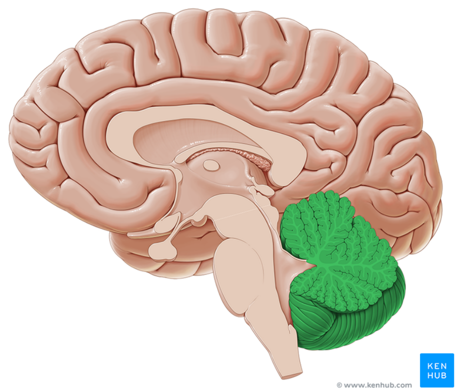
This subgroup has two major divisions called the **pars olaris** located anteriorly and **pars caudalis** located posteriorly. The ventral lateral nucleus **relays information** with several areas:

- Pars olaris
  - Ipsilateral internal pallidum (**afferent**)
  - Supplementary motor cortex (**efferent**)
  - Lateral premotor cortex (**efferent**)
- Pars caudalis
  - Contralateral deep cerebellar nuclei (**afferent**)

- Area 4 of primary motor cortex (**efferent**)

- Overall ventral lateral nucleus
  - Spinothalamic tract (**afferent**)
  - Vestibular nuclei (**afferent**)
  - Precentral motor cortex (**afferent**)

The ventral lateral nucleus is active during both passive and active **movement** of the contralateral part of the body. It also has a role in **relaying motor feedback** from the cerebellum to the cerebral cortex.



Cerebellum - medial view

Ventral Posterior Nucleus

The ventral posterior nucleus is the **principal thalamic relay** for the somatosensory pathways and it is subdivided into two parts: **ventral posteromedial** and **ventral posterolateral**. This nucleus establishes several **neuronal pathways** with different regions within the brain:

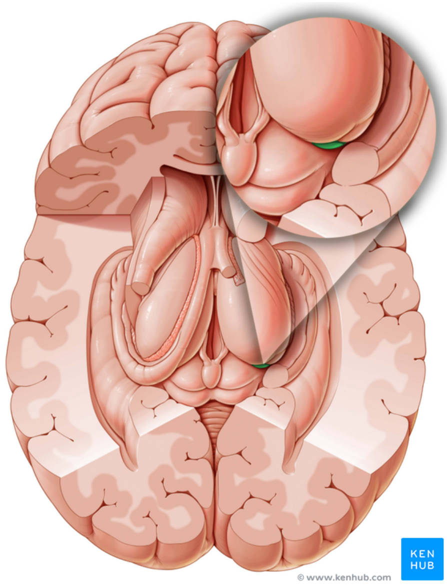
- Ventral posterolateral
  - Medial lemniscal pathway (**afferent**)
  - Spinothalamic pathway (**afferent**)
- Ventral posteromedial
  - Trigeminothalaimc pathway (**afferent**)
- Overall ventral posterior nucleus
  - Areas 1 and 3b of the primary somatic sensory cortex (**efferent**)
  - Second somatic sensory cortex (**efferent**)
  - Insular cortex (**efferent**)

The **trigeminothalamic pathway** brings temperature and pain sensations from the face, head and neck. In turn, the **medial lemniscal** and **spinothalamic pathways** bring sensory information from the skin and joints. Neurons receiving the inputs are organised into **curved lamellae**, with one lamella usually representing one region of the body. Within one lamella, different regions receive inputs distinguished by the level of **sensorial "depth"**. For instance, when referring to the hand, the anterodorsal part receives information from deep stimuli such as joint, tendon and muscle movement. These are the deepest source. The ventral part receives more superficial stimuli from tapping, while the neurons located between these two parts receive the most superficial inputs, such as cutaneous touch.

The **efferent fibers** running to the somatosensory cortex pass through the posterior limb of the **internal capsule** and **corona radiata**. This illustrates their involvement in **relaying sensory sensations** for conscious identification.

Medial geniculate nucleus

The **medial geniculate nucleus** is located within the **medial geniculate body**. The latter is a swelling on the posterior surface of the ventrolateral surface of the thalamus located underneath the pulvinar.



Medial geniculate nucleus - cranial view

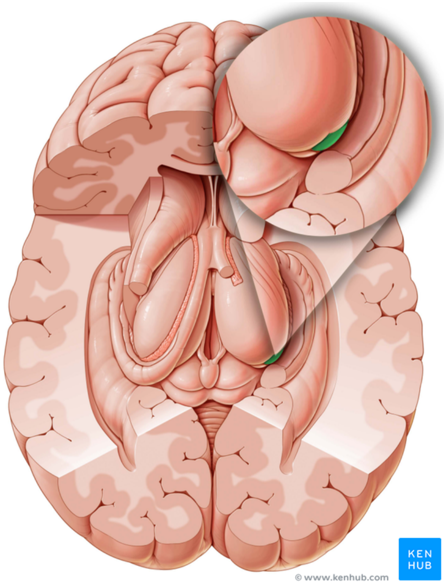
There are three major subnuclei associated with this nucleus: **medial**, **ventral** and **dorsal**. The medial nucleus is separated from the thalamus by the inferior brachium. The dorsal nucleus overlies the ventral one and expands posteriorly. The **communications** of the medial geniculate nucleus are as follows:

- Ventral nucleus
  - Central nucleus of the ipsilateral and contralateral inferior colliculus (**afferent**)
  - Primary auditory cortex (**efferent**)
- Dorsal nucleus
  - Pericentral nucleus of the inferior colliculus (**afferent**)
  - Brainstem nuclei of auditory pathways (**afferent**)
  - Auditory areas around the primary auditory cortex (**efferent**)
- Medial nucleus
  - Inferior and superior colliculus (**afferent**)
  - Cortical auditory area (**efferent**)
  - Insular and opercular cortical fields (**efferent**)

The medial geniculate forms part of the **auditory pathway** and is responsible for hearing.

Lateral geniculate nucleus

The **lateral geniculate nucleus** is located within the **lateral geniculate body**. The body is an ovoid projection from the posterior thalamus. The nucleus consists of six to eight laminae, which are separated by interlaminar zones. The laminae are located terminally on the **optic tract** and receive information from the ganglionic cell layer of the retina of both eyes.



Lateral geniculate nucleus - cranial view

The **communicating fibers** entering and leaving the lateral geniculate nucleus are as follows:

- Contralateral nasal hemiretina to laminae 1,4 and 6 (**afferent**)
- Ipsilateral temporal hemiretina to laminae 2,3 and 5 (**afferent**)
- Area 17 of primary visual cortex (**efferent**)
- Extrastriate visual areas in in the occipital lobe (**efferent**)

The lateral geniculate nucleus is responsible for **vision**.

Intralaminar nuclei

These are collections of nerve cells within the **internal medullary lamina**, the "Y" shaped white matter sheet discussed before. There are two groups of nuclei involved: the **anterior** (rostral) and **posterior** (caudal).

Anterior group

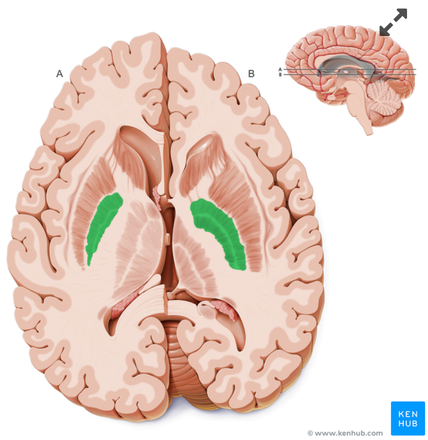
The **anterior group** consists of subdivisions, namely the **central medial**, **paracentral** and **central lateral nuclei**. These nuclei have several connections:

- Central medial
  - Orbitofrontal cortex (**reciprocal**)
  - Prefrontal cortex (**reciprocal**)
  - Cortex on the medial surface (**reciprocal**)
- Paracentral
  - Occipitotemporal (**reciprocal**)
  - Prefrontal cortex (**reciprocal**)

- Central lateral
  - Parietal association area (**reciprocal**)
  - Temporal association area (**reciprocal**)
  - Spinothalamic tract (**afferent**)
- Overall anterior group
  - Striatum (**efferent**)
  - Brainstem reticular formation (**afferent**)
  - Superior colliculus (**afferent**)
  - Pretectal nuclei (**afferent**)

Posterior group

The **posterior group** is subdivided into **centromedian** and **parafascicular nuclei**. The centromedian nucleus is related to the globus pallidus, deep cerebellar nuclei and motor cortex. The smaller parafascicular nucleus lies more medially within the lamina. The **connections** of the posterior group are as follows:



Globus pallidus - cross-sectional view

- Motor areas (**reciprocal**)
- Premotor areas (**reciprocal**)
- Supplementary motor (**reciprocal**)
- Striatum (**efferent**)
- Internal palladium (**afferent**)
- Pars reticularis of substantia nigra (**afferent**)
- Deep cerebellar nuclei (**afferent**)
- Pedunculopontine nuclei (**afferent**)
- Spinothalamic tract (**afferent**)

The intrathalamic nuclei play a role in **activation of the cortex** from the brainstem reticular formation. It is also involved in **sensory-motor integration**. The posterior intrathalamic nuclei also seem to be important in **speaking** and **motivation**.

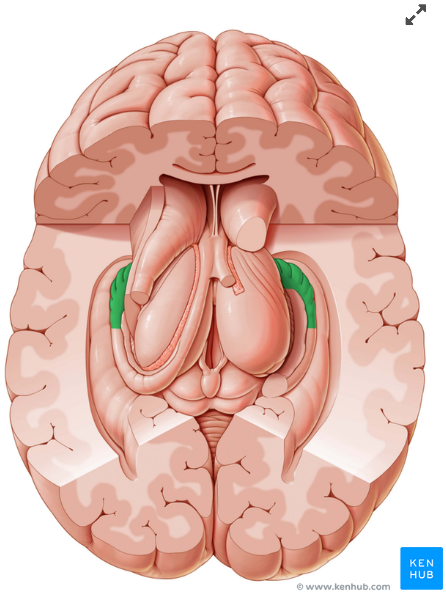
Midline nuclei

The midline nuclei can be divided into three: **rhomboid**, **reuniens** and **parataenial nuclei**. The entire group is located ventrally to the central medial nucleus. Their **communications** are as follows:

- Hypothalamus (**afferent**)

- Periaqueductal grey matter of the midbrain (**afferent**)
- Spinothalamic tract (**afferent**)
- Medullary reticular formation (**afferent**)
- Pontine reticular formation (**afferent**)
- Hippocampal formation (**efferent**)
- Amygdala (**efferent**)
- Nucleus accumbens (**afferent**)
- Cingulate (**reciprocal**)
- Orbitofrontal cortex (**reciprocal**)

As illustrated by their connections, the midline nuclei are important in the **limbic system**. In addition, they may also play a role in **memory** and **arousal**.



Hippocampus - cranial view

Reticular nucleus

The **reticular nucleus** is a curved lamella of cells that wraps around the the lateral margin of the thalamus. It is separated from it by the external medullary lamina. Anteriorly, it curves around the rostral pole of the thalamus. This nucleus receives collateral branches from major fibers which transverse it. These include **corticothalamic**, **thalamocortical**, **thalamostriatal** and **pallidothalamic**. The reticular nucleus is the only thalamic nucleus that does not project primarily to the cerebral cortex. In terms of specific afferent and efferent pathways, the reticular nucleus is **connected** as follows:

- Nucleus cuneiformis of the midbrain (**afferent**)
- Body of the thalamus (**efferent**)

Cells within the reticular nucleus respond to **visual**, **somatic** and **auditory stimuli**. Also, this nucleus is involved in gating or **filtering information** relayed through the thalamus.

Clinical points

Thalamic lesions

Lesions of the thalamus are possible due to thrombosis or hemorrhage of one of the arteries supplying the thalamus. Damage to the ventral posteromedial and ventral posterolateral nuclei results in the loss of all forms of sensation. Due to its central location, thalamic lesions lead to dysfunctions in surrounding areas.

For instance, a vascular lesion to the thalamus can involve the midbrain and result in coma. Effects resulting specifically from thalamic lesions include choreoathetosis with ataxia, otherwise known as involuntary movements and loss of balance.

Surgical pain relief

Surgical pain relief is often performed through cauterization of the intralaminar nuclei of the thalamus for severe and intractable pain associated with terminal cancer.

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- Lateral geniculate nucleus – cranial view – Paul Kim
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