CHAPTER 15
Diencephalon

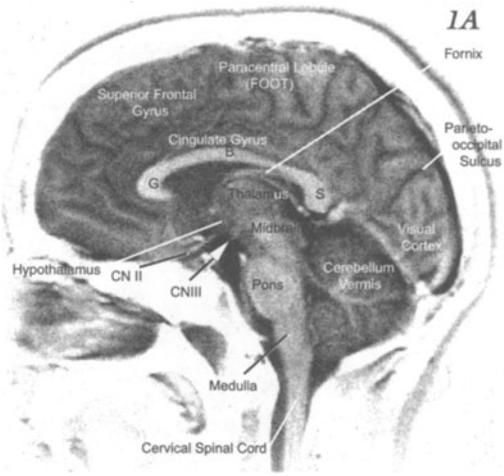
The diencephalon appears as a large region at the upper end of the brain stem. All the ascending fiber pathways from the spinal cord and brain stem terminate upon nuclei in the diencephalon. From these nuclei the information is relayed onto the cerebral cortex.

Due to the convergence of all major ascending sensory, motor and reticular systems consciousness for general sensations are first realized at this level. In addition, the ascending motor information from the cerebellum mixes with the striatal and cortical motor fibers in the dorsal thalamus producing a motor thalamic region. Finally, the hypothalamus and limbic cortical regions have major input onto the dorsomedial nucleus of the thalamus.

I. DIENCEPHALIC BOUNDRIES

The border between the diencephalon and the midbrain is indistinct and may be arbitrarily defined by passing a line from the inferior surface of the mammillary bodies to the posterior border of the habenula. Portions of the substantia nigra and red nucleus are also seen in the posterior portion of the diencephalon.

In order to identify the majority of the nuclei in the diencephalon and basal nuclei the cerebral cortex and corpus callosum are carefully separated and removed revealing the diencephalon *(Fig 15-1)*. Then one finds the slit-like third ventricle in the midline. At the rostral end of the diencephalon we can identify the anterior tubercle (containing the anterior thalamic nuclei) and at the posterior margin the pulvinar. The major new white matter bundles at this level are the internal capsule, fornix, and stria terminalis. The basal nuclei of the cerebrum can now also be visualized *(Figure 15-2)*, and consist of caudate, putamen and globus pallidus. The globus pallidus is found lateral to the internal capsule, and the putamen is adjacent to it. The caudate nucleus is found medial to the internal capsule. In the posterior levels of the diencephalon, the caudate is relatively small, but as one proceeds anteriorly, the diencephalon becomes smaller and the caudate enlarges.



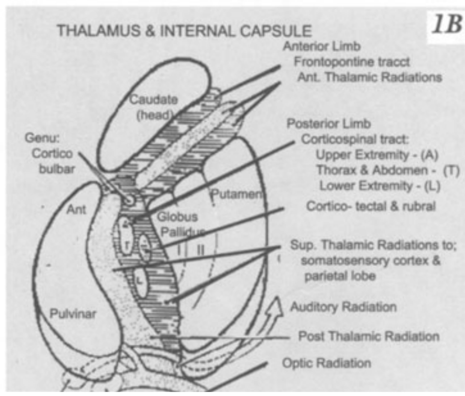


Figure 15-1. Brain in Sagital plain demonstrating. The relationship between brain stem, diencephalon and cerebrum. (MRI weighted T1.) Location of thalamus. A. MRI B. Gross Brain..

The body of the lateral ventricle along with the corpus callosum and fornix form the superior border of the diencephalon (Fig. 15-3). The posterior limb of the internal capsule and the optic tract mark its lateral boundary, and the slit-like third ventricle denotes its medial border. Inferiorly, the diencephalon is continuous with the tegmentum of the midbrain, while rostrally it ends at the lamina terminalis.

The tegmentum of the midbrain is continu-

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ous with the hypothalamus *(Fig 15-4)*. The diencephalon consists of five distinct nuclear subdivisions: thalamus, epithalamus, hypothalamus, metathalamus, and subthalamus (Figure 15-2). As can be seen from the terminology associated with the diencephalon, all structures are described by their spatial relationship to the thalamus, being above, below, or behind them. The epithalamus and hypothalamus are discussed in Chapter 16.

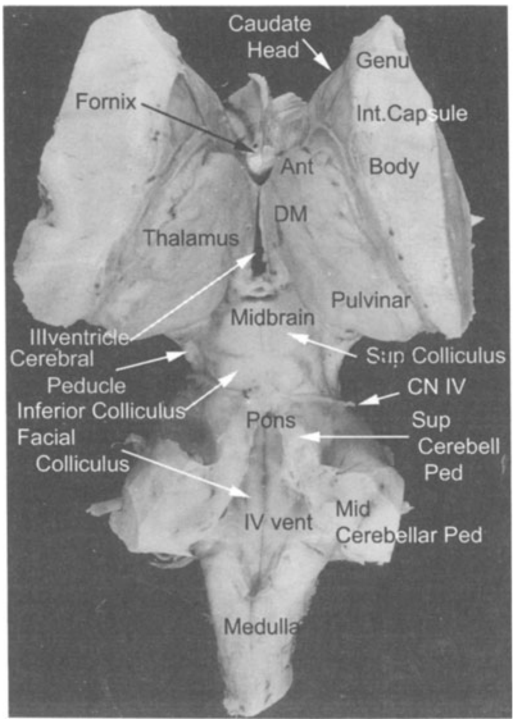

Figure 15-2. Dorsal view of gross specimen of brain stem, diencephalon, and basal ganglia. Medulla, pons, midbrain, thalamic regions and internal capsule labeled.

II. NUCLEI OF THE THALAMUS

The thalamus and metathalamus is the major relay center between the brain stem and the cerebral cortex. The thalamus is the largest portion of the diencephalon. It is ovoid in shape; the posterior limb of the internal capsule, medially by the third ventricle, bound it laterally inferiorly by the subthalamus and hypothalamus, and superiorly by the body of the lateral ventricle and corpus callosum. The boundary between the thalamus and hypothalamus (Fig 15-3) is the hypothalamic sulcus on the medial wall of the diencephalon about a third of the way up from the floor of the third ventricle. All nuclear structures superior to the sulcus are included in the dorsal thalamus, and all nuclei below it are included in the hypothalamus *(Fig. 15-3)*.

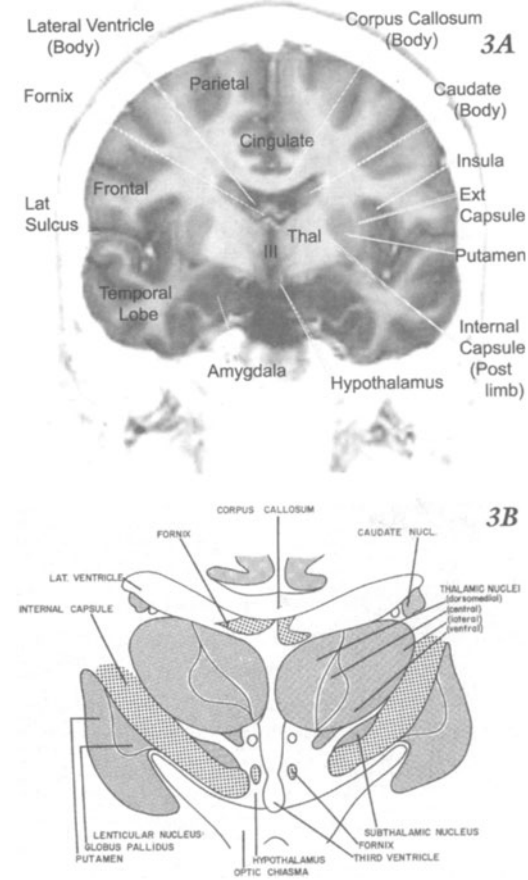

Figure 15-3. Mid thalamic level. A. MRI B. Schematic coronal section showing nuclei of thalamus, hypothalamus, subthalamus, basal ganglia and the white matter internal capsule.

Thalamic Borders. The external medullary lamina forms the lateral boundary of the thalamus, and separates it from the reticular nucleus of the thalamus. There is also an intrinsic bundle of white matter, the internal medullary lamina, which divides the thalamus into three major nuclear masses the anterior, medial and lateral. The anterior mass includes the anterior nuclei; the medial mass includes the dorsomedial nuclei and the midline nuclei, with the lateral mass including all of the other nuclei. Cell and fiber

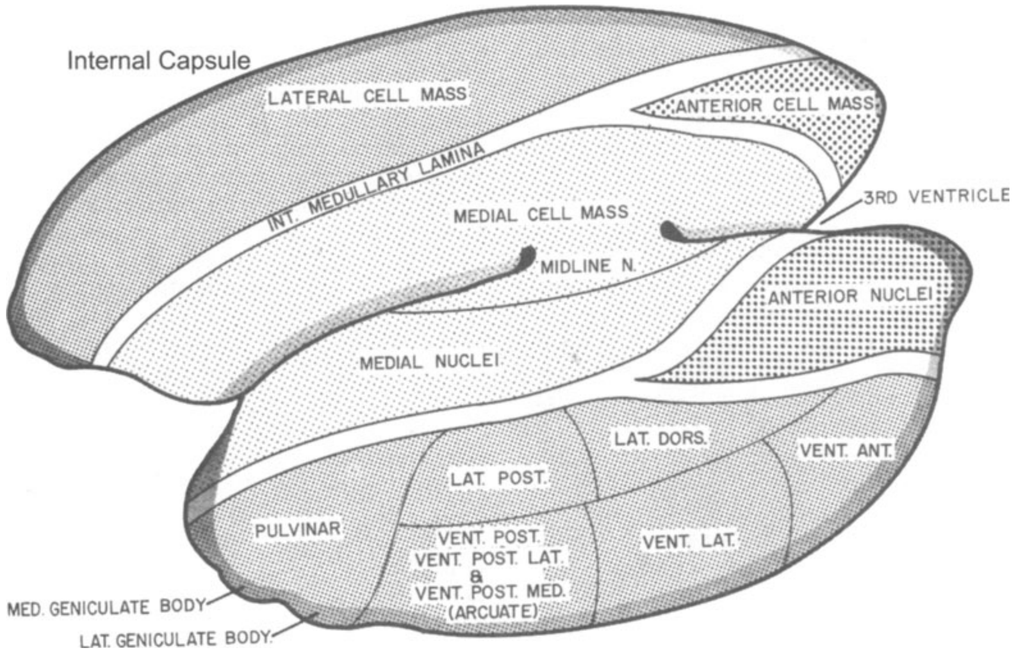

Figure 15-4. 3D Reconstruction of the thalamic nuclei with the upper portion showing the three major nuclear subdivisions and the lower portion showing individual nuclei. Modified After Carpenter Core Text, *Williams& Wilkins 1992*

stains are used to further subdivide the thalamus. With these stains the following nuclei are identifiable: anterior, medial, midline, intralaminar, lateral, posterior, reticular, and metathalamus. Each of these nuclear groupings can be further subdivided as follows Table 15-1; Nuclei in the Thalamus

III. FUNCTIONAL ORGANIZATION OF THALAMIC

A. SENSORY AND MOTOR RELAY NUCLEI-THE VENTROBASAL COMPLEX, LATERAL POSTERIOR, (FIGURE 15-4).

These nuclei *(Fig 15-4)* are part of the somatic brain as they receive direct input from the ascending sensory and motor systems, from the cerebellum, and from the optic tract.

The special sensory medial and lateral geniculate nuclei are discussed below.

The lateral nuclear mass is divided into three parts: lateral dorsal, lateral posterior, and pulvinar. It occupies the upper half of the lateral nuclear grouping throughout the thalamus. It is bounded medially by the internal medullary lamina of the thalamus and laterally by the external medullary lamina of the thalamus. In a stained preparation its ventral border with the ventral nuclear mass is distinct. The lateral nuclear mass starts near the anterior end of the thalamus and runs the length of the thalamus with its posterior portion, the pulvinar, overhanging the geniculate bodies and the midbrain.

The lateral posterior part of the lateral nuclear mass projects to the superior parietal lobule and receives input from specific thalamic nuclei. The lateral dorsal part is included above with the limbic nuclei.

The ventral basal nuclear mass consists of three distinct regions: ventral anterior, ventral lateral, and ventral posterior. The *ventral anterior* nucleus (VA) is the smallest and most rostral nucleus of this group. It can be identified by the presence of numerous myelinated bundles. The magnocellular portion of this nucleus receives fibers from the globus pallidus, via the lenticular and thalamic fasciculi, and from the intralaminar nuclei and has some projections to areas 4 and 6. Stimulation of this nucleus produces the same effects as stimulation of the intralaminar nuclei.

The ventral lateral and ventral posterior nuclei contain cell bodies that project onto the

TABLE 15-1: NUCLEI IN THE THALAMUS

A. ANTERIOR NUCLEI (Limbic)
1. Anterior dorsal
2. Anterior medial
3. Anterior ventral (Anterior principalis)

B. MEDIAL NUCLEI (Limbic & Specific Associational)
1. Nucleus medialis dorsalis
a. Pars parvocellulares
b. Pars magnocellularis

C. MIDLINE NUCLEI (Non specific Associational)
1. Nucleus parataenialis
2. Nucleus paraventricularis
3. Nucleus reuniens
4. Nucleus rhomboideus

D. INTRALAMINAR NUCLEI - in the internal medullary lamina (Nonspecific Associational)
1. Nucleus centrum medianum
2. Nucleus parafascicular
3. Nucleus paracentralis
4. Nucleus centralis lateralis
5. Nucleus centralis medialis

E. LATERAL NUCLEI
1. Pars dorsalis (Specific Associational)
a. Nucleus lateralis posterioris
b. Nucleus lateralis dorsalis
c. Pulvinar
(1) Pars inferioris
(2) Pars lateralis
(3) Pars medialis
2. Pars ventralis/Ventrobasal complex (Motor & Sensory Relay).
a. Ventralis anterior
b. Ventralis lateralis
c. Ventralis ventralis
d. Ventralis posterior
(1) Posterolateral
(2) Posteromedial

F. RETICULAR NUCLEI (Nonspecific Associational)

G. METATHALAMIC NUCLEI (Sensory Relay)
1. Lateral geniculate (Vision-opticothalamic)
2. Medial geniculate (Audition-auditothalamic)

H. POSTERIOR NUCLEI (Nonspecific Associational)
1. Limitans
2. Suprageniculate
3. Posterior (Nociceptive System)

motor and sensory cortex. In the thalamus the head is found medial and posterior and the leg anterior and lateral. The *ventral lateral* nucleus (VL, somatic motor thalamus) occupies the middle portion of the ventral nuclear mass. It is a specific relay nucleus in that it receives fibers from the contralateral deep cerebellar nuclei (via the superior cerebellar peduncle/ dentatorubrothalamic tract) and the ipsilateral red nucleus. This nucleus also receives fibers from the globus pallidus and from the intralaminar nuclei. This nucleus projects to area 4 and to area 6 and has a topographic projection to the motor cortex. This nucleus is important in integrative somatic motor functions because of the interplay between the cerebellum, basal ganglia, and cerebrum in this nucleus.

The *ventral posterior* nucleus occupies the posterior half of the ventral nuclear mass and consists of two parts: the ventral posterior medial nucleus and the ventral posterior lateral nucleus. Both of these nuclei receive input from the specific ascending sensory systems.

The *ventral posterior medial* nucleus (VPM, the arcuate, or semilunar, nucleus) is located lateral to the centromedian nucleus and medial to the ventral posterior lateral nucleus. The secondary fibers of the trigeminal and gustatory pathways terminate in this nucleus; thus this nucleus is concerned primarily with taste and with general sensation from the head and face. The basal region of the ventromedial nucleus receives the taste fibers and probably some of the vagal input. General sensation from the face, including pain, temperature, touch, pressure, and proprioception, terminate in the other portions of this nucleus. This nucleus projects information from the face, ears, and head, and tongue regions onto the inferior part of the postcentral gyrus, areas 3, 1, 2

The *ventral posterior lateral* (VPL) nucleus receives fibers from the posterior columns and the direct spinothalamic tracts with the bulk of the input originating in the upper extremity. The VPL nucleus projects to the body and neck regions on the postcentral gyrus (areas 3, 1, 2).

B. LIMBIC NUCLEI - THE ANTERIOR, MEDIAL, LATERAL DORSAL, MIDLINE AND INTRALAMINAR NUCLEI *(Fig 15-9).*

The limbic nuclei may also be called the nuclei of the emotional brain.

The *anterior nuclei* (15-4) are at the most rostral part of the thalamus and form the prominent anterior tubercle in the floor of the lateral ventricle. The tubercle includes a large main nucleus (anteroventral) and small accessory nuclei (anterodorsal and anteromedial).

The internal medullary lamina of the thalamus surrounds the anterior nuclei. The mammillothalamic fibers form the bulk of the fibers in the internal medullary lamina. This zone is an important relay station in the limbic brain and receives input from the subiculum, presubiculum and mammillary body via the mammillothalamic tract.

The anterior nuclear complex is part of the Papez circuit: (hippocampal formation --> fornix --> mammillary body --> mammillothalamic tract --> anterior thalamic nucleus --> anterior thalamic radiation --> cingulate cortex --> cingulum --> perforant pathway -->hippocampus). This nucleus projects to the anterior cingulate gyrus (areas 23, 24, 32) and receives input from the hypothalamus, habenula, and cingulate cortex. Stimulation or ablation of this nuclear complex alters blood pressure and may have an effect on memory.

The *lateral dorsal* nucleus, like the anterior nucleus, is surrounded by the rostral portion of the internal medullary lamina of the thalamus and should be considered a caudal continuation of the anterior nuclear group. This nucleus projects to the rostral cingulate cortex and onto the parahippocampal gyrus.

The medial nuclear complex or the *dorsomedial* nucleus consists of both a large-celled and a small-celled division. This medial region is found between the internal medullary laminae and the midline nuclei lining the third ventricle *(Fig. 15-5)*. The *magnocellular* portion of the dorsomedial nucleus is interconnected with the hypothalamus, amygdala, and midline nuclei and connects to the orbital cortex; the large *parvicellular division* is interconnected with the temporal, orbitofrontal and prefrontal cortices (areas 9, 10, 11, 12; see Chapter 22)

The medial nuclear complex is an important relay station between the hypothalamus, amygdala and the prefrontal cortex and is concerned with the multimodal associations between the limbic (visceral) and somatic impulses that contribute to the emotional makeup of the individual. Destruction of this nucleus in cats results in a lower threshold for rage, so that the animal is easily aroused. In human beings, ablation of the medial nucleus or a prefrontal lobotomy has been used as a therapeutic procedure to relieve emotional distress (SEE CHAPTER 22).

C. SPECIFIC ASSOCIATIONAL- MULTIMODAL/ SOMATIC NUCLEI-THE PULVINAR NUCLEI (fig 15-4).

The Pulvinar Nuclei

The pulvinar (Fig 15-4) is the largest nucleus in the thalamus and is continuous with the posterior part of the lateral division. All the major ascending sensory pathways have some terminations in the medial and lateral nuclei. The pulvinar therefore is the major multimodal association nucleus of the thalamus integrating sensory, motor, visual, and limbic information.

The pulvinar is divided into three major nuclei: the medial pulvinar nucleus, the lateral pulvinar nucleus and the inferior pulvinar nucleus. The *medial pulvinar* nucleus projects onto the prefrontal and anterior temporal limbic cortex. The lateral pulvinar nucleus projects onto supramarginal, angular, and posterior temporal lobe. The *inferior pulvinar* nucleus is related to the visual system and projects onto the visual association cortex, areas 18 and 19. Because of the strong projections of the lateral pulvinar nucleus onto the cortex surrounding the posterior end of the lateral sulcus, lesions in the pulvinar in the dominant hemisphere produce disturbances in language.

E. SPECIAL SENSORY NUCLEI-METATHALAMUS: VISION AND AUDITION, THE LATERAL GENICULATE and MEDIAL GENICULATE Nuclei (Fig 15-4.

AUDITION (Also see Chapter 22)

The *medial geniculate* nucleus (MGN) is located on the most caudal portion of the thalamus receives the ascending auditory fibers originating from the following nuclei: cochlear, trapezoid, superior olivary, lateral lemniscal, and inferior colliculus. The auditory fibers end on the medial geniculate pars parvocellulares. Vestibular fibers end in the magnocellular portion of the medial geniculate and are projected onto postcentral gyrus. This nucleus projects to area 41 in the temporal lobe, the transverse temporal gyrus of Heschl. The ventral nucleus of the medial geniculate receives input from the inferior colliculus.

VISION (Also see Chapter 23)

The *lateral geniculate* nucleus (LGN) is a horseshoe-shaped six-layered nucleus with its hilus on its ventromedial surface. The LGN receives the optic tract and projects to areas 17 and 18. Figure 15-5 demonstrates the visual radiation onto the calcarine cortex of the occipital lobe). This nucleus contains the six neuronal layers separated by bands of myelinated axons. The four outer layers contain small- to medium-sized cells, that project onto layer iv of the striate cortex with the two innermost layers contain large cells (magnocellular) projecting onto layer I and deep portion of layer IV.

Crossed fibers of the optic tract terminate in laminae 1, 4, and 6, while uncrossed fibers end in laminae 2, 3, and 5. This nucleus also connects with the inferior pulvinar, ventral, and lateral thalamic nuclei. Some optic fibers proceed directly to the pretectal area and the superior colliculus with or without synapsing in the lateral geniculate nucleus. There they partake in the light reflex and accommodation reflex (see Chapter 21).

F. NON-SPECIFIC ASSOCIATIONAL.

The thalamic reticular nucleus forms a cap around the thalamus, medial to the internal capsule. All fibers systems leaving the thalamus and projecting onto the cerebral cortex and the fibers coming back from these same cortical areas pass through this nuclear complex with many specific systems terminating in this nucleus. This nucleus contains GABA-ergic neurons and has a modulating effect on thalamic neurons.

The *midline thalamic* nuclei (Fig. 15-4) are located in the periventricular gray above the hypothalamic sulcus. They are small and difficult to delimit in human beings, but these nuclei are intimately connected to the hypothalamus and the intralaminar nuclei, and their function must be interrelated.

The *intralaminar* nuclei (Figs. 15-3 and 15-5) are found in the internal medullary laminae of the thalamus. The most prominent intralaminar nucleus is the posteriorly placed centromedian, which is located in the midthalamic region between the medial and ventral posterior nuclei and receives many nociceptive fibers. The *parafascicular* nucleus is also easily delimited because it is at the dorsomedial edge of the habenulopeduncular tract. The intralaminar nuclei receive input from many regions throughout the central nervous system, including ascending axons from the reticular nuclei, indirect spinothalamic pathways, midbrain limbic nuclei, subthalamus, hypothalamus as well as other thalamic nuclei. The intralaminar nuclei have some direct projections onto the frontal lobe however their major influence is on the cerebral cortex by their connections to the specific thalamic nuclei.

Electrical stimulation of the intralaminar nuclei activates neurons throughout the ipsilateral cerebral hemisphere. As the stimulation continues, more and more cortical neurons fire, which is called the recruiting response, and there is a waxing and waning, the response finally peaks then decreases but may increase again. The centromedian nucleus has a strong projection to ventral anterior and ventral lateral nuclei and has

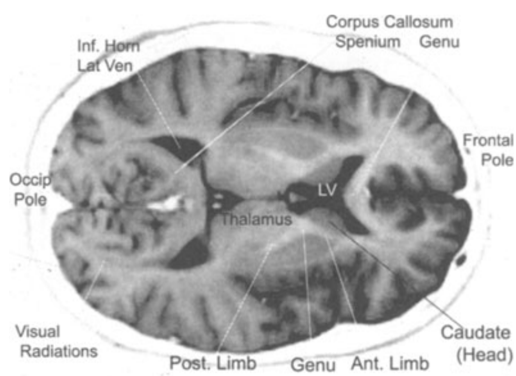

Figure 15-5. Horizontal section, demonstrating the anterior limb, genu, and posterior limb of the internal capsule. Note the putamen and globus pallidus are external to the internal capsule. (MRI weighted T2.)

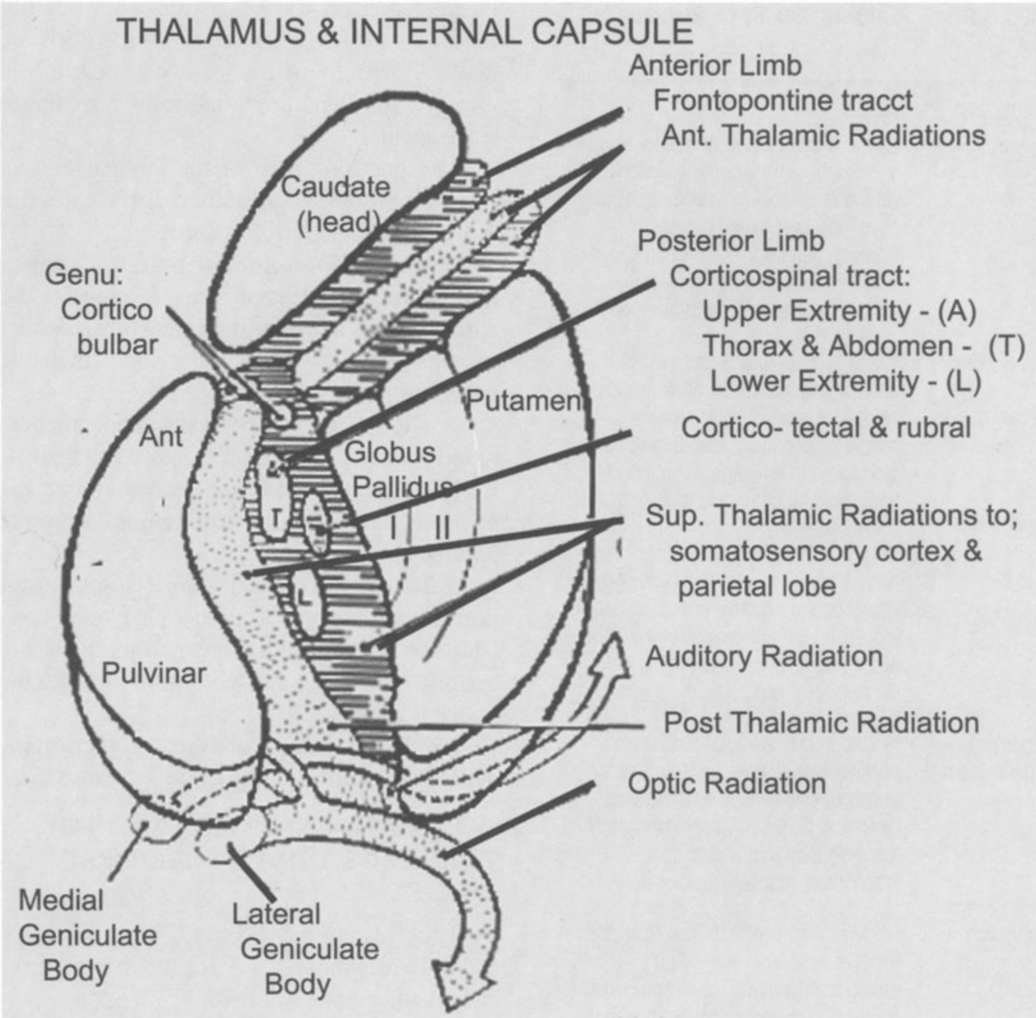

Figure 15-6. A horizontal section similar to 15-6. The major fiber tracts of the in the right internal capsule are labeled. Modified After Carpenter Core Text, Willams & Wilkins 1992.

a direct projection to the caudate and putamen which permits interrelationship with the extrapyramidal motor system (see Chapter. 17).

In Table 15-2, the principal thalamic nuclei are grouped as to the type of modality that reaches the individual nuclei. This table demonstrates that the thalamus receives input from gray matter in the spinal cord, brain stem, cerebellum and cerebrum. The type of input is identified functionally as sensory, motor, limbic or associational.

III. WHITE MATTER OF THE DIENCEPHALON

At the lateral margin of the diencephalon is the major white matter bundle that connects the diencephalon and the cerebrum, internal capsule.

Internal Capsule (Fig 15-6).

The internal capsule is a large myelinated region that marks the border between the diencephalon and telencephalon. The internal capsule, consisting of the anterior limb, genu, and posterior limb, is best visualized in a horizontal section, where it forms an obtuse angle. All fibers projecting from the thalamus onto the cerebral hemispheres must pass through this region, while all fibers leaving the cerebral cortex and going either to the diencephalon, basal nuclei, brain stem, or spinal cord must also pass through its parts. In the following diagrammatic horizon-

TABLE 15-2. FUNCTIONAL GROUPS OF THALAMIC NUCLEI

Modality	Nuclei
Sensory Relay	Nuclei: ventral posterior medial (touch and taste), ventral posterior lateral (touch & vestibular), medial geniculate (hearing), and lateral geniculate (vision). Input from ascending specific sensory modalities and project to cortical area subserving that modality.
Motor Relay	Nuclei: ventral lateral and ventral anterior. Input from the contralateral cerebellar hemispheres, superior cerebellar peduncle, medial globus pallidus, and the nigrostriatal fibers from the area compacta of the substantia nigra.
Limbic	Nuclei: dorsal medial, anterior, and lateral dorsal, Receive a well defined input from the mammillothalamic tract of the Papez circuit and project onto the prefrontal and cingulate gyrus.
Specific Associational	Nuclei: dorsal medial, lateral, and pulvinar nuclei. Forms the bulk of the thalamus and receive a multimodal input and projects onto cortical areas that also receive a multimodal intracortical associational input.
Nociceptive	Nuclei: Dorsomedial, VPL & Posterior. Receive input from ascending anterolateral system, spinothalamic, spinoreticular and spinomesencephalic
Nonspecific Associational	Nuclei: intralaminar, midline, and reticular. Receive input from diverse subcortical regions, including the reticular formation, visceral brain, and corpus striatum, project to specific thalamic nuclei or associational areas in the cortex.

tal section the three major parts of the internal capsule are identified and their constituent fiber systems discussed: the anterior limb, genu and posterior limb *(Figure 15-6)*.

The anterior limb lies between the caudate nucleus and putamen, and this portion of the capsule contains the anterior thalamic radiation and the frontopontine fibers.

The genu is found at the rostral end of the diencephalon on the lateral wall of the lateral ventricle and is the point at which the fibers are displaced laterally by the increasing bulk of the diencephalon. The corticobulbar fibers are found in the genu.

The posterior limb of the internal capsule consists of three subdivisions: thalamolentiform, sublenticular, and retrolenticular:

1. The *thalamolenticular* portion (between the thalamus and lenticular nuclei) contains the corticospinal, corticorubral, corticothalamic, thalamoparietal, and superior thalamic radiations.

2. The *sublentiform* portion (passing inferiorly and posteriorly) includes the posterior thalamic radiations that include optic radiation (Fig. 15-6), acoustic radiation, corticotectal, and temporal pontine fibers.

3. The *retrolenticular* portion (passing posteriorly into the temporal and occipital lobes) contains the posterior thalamic radiation to the occipital and temporal lobes and the parieto-occipital fasciculus.

Within the diencephalon many other myelinated fiber bundles can be identified Table 15-3.

IV. RELATIONSHIP BETWEEN THE THALAMUS AND THE CEREBRAL CORTEX. FIG 15-7.

The thalamus has several major roles;

1) To receive input from the brain stem, cerebellum and corpus striatum,

2) To project this information, after some processing, onto the cerebrum, and

3) To receive reciprocal projections from the same cerebral areas. The relationship between many thalamic nuclei and specific cortical areas is so intimate that when a cortical region is destroyed the neurons in a particular thalamic nucleus atrophy (Walker 1938). This degeneration is a consequence of the thalamic projection and its reciprocal from the cortex, being restricted to only a single specific cortical region and is seen in portions of the following nuclei: anterior, ventral lateral, ventral posterior, lateral geniculate, medial geniculate, and magnocellular portion of the medial dorsal. and pulvinar. The intralaminar, midline, posterior, portions of the pulvinar, and medial nuclei are unaffected by cortical lesions.

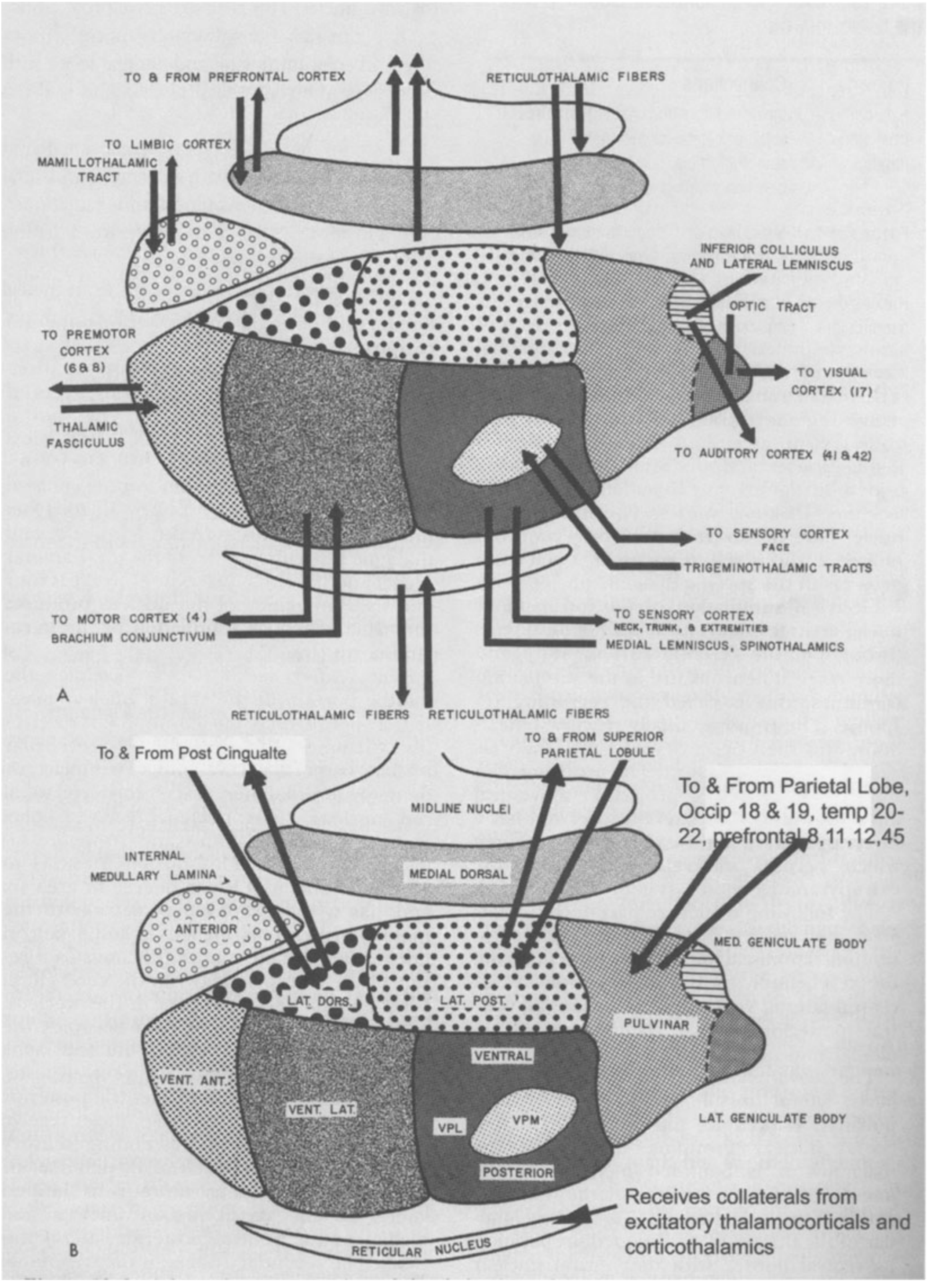

Figure 15-7; Representation of the thalamic nuclei: A- showing connections of ventrobasal, midline, anterior, lateral nuclei and geniculate nuclei. B- demonstrating connections of lateral dorsal, lateral posterior and pulvinar nuclei.. (After Truex, R.C., and Carpenter, M.B.: Human Neuroanatomy. Baltimore, Williams and Wilkins, 1970)

TABLE 15-3: MAJOR FIBER BUNDLES ASSOCIATED WITH THE DIENCEPHALON:

Pathway	Connections
External medullary lamina	Includes fibers from medial lemniscus, superior cerebellar peduncle, spinothalamics, and pathways between cortex and thalamus
Fornix	Subiculum and hippocampus to septum & hypothalamus (Part of Papez Circuit)
Habenulo-peduncular	Habenula to interpeduncular nucleus and tegmentum of midbrain
Internal capsule includes: Anterior limb, genu, posterior limb	Thalamus and cerebral cortex, and cerebral cortex to brain stem and spinal cord
Internal medullary lamina	Contains mammillothalamic, ascending reticular and spinothalamic fibers.
Mammillo-thalamic	Mammillary bodies with anterior thalamic nuclei (Part of Papez Circuit)
Mammillary peduncle	Mammillary nuclei with tegmentum of midbrain

Thalamic input onto the cortical layers.

The most important input the cerebral cortex receives is from the thalamus. The densest input from the specific relay projectional nuclei (e.g. VPL, VPM) is to layer 4, but as indicated above, pyramidal cells in layers 3 and 5 many also receive direct or indirect inputs. There is a modality specific columnar arrangement. With many nuclei having an extensive input onto the cortex there is always a reciprocal cortical input. The nonspecific nuclei (midline & intralaminar) have a more diffuse input and project onto layer I.

Thalamic Radiations and the Internal capsule.

The fibers that reciprocally interconnect the cortex and the thalamus form the thalamic radiations *(Fig 15-6)*. The thalamic radiations are grouped in the internal capsule into 4 peduncles: anterior, superior, posterior and inferior.

Anterior radiations- connects frontal lobe and cingulate cortex with median and anterior thalamic nuclei. This is an extensive projection.

Superior radiations- connects motor sensory strip and adjacent frontal and parietal lobes with fibers from the ventrobasal nuclei. This is also a large projection.

Posterior radiation- connects occipital and posterior parietal areas with pulvinar, and lateral geniculate nucleus (geniculocalcarine radiations - optic radiations). This is an extensive radiation due to the optic radiations.

Inferior radiations- connections from medial geniculate (auditory radiations) and pulvinar with temporal lobe. This is the smallest group of fibers between the thalamus and cortex.

In *Figure 15-7* the afferents and efferents of the individual thalamic nuclei are presented.

In *figure 15-8* we have shown the cortical projections of the same thalamic nuclei.

In f*igures 15-9, 15-10, 15-11,* and *15-12* we discuss the major afferent pathways to the thalamus and metathalamus.

In the table that follows, Table 15-4, we have summarized the cortical projections of the major thalamic nuclei and also included the functions of these regions.

Other Possible Inputs to Thalamus. In addition to the major pathways discussed above there are other subcortical sources of input onto the cerebral cortex that pass through the diencephalon, and they may well have modulating effects on the thalamus (see discussion in chapter 17) these include:

1. *Noradrenergic* (norepinephrine) pathway from the locus ceruleus of the midbrain projecting in primates predominantly to layer 6 of the motor and somatosensory cortex and related frontal and parietal association cortex.

2. *Serotoninergic* pathway from the raphe nuclei in the pons and medulla and the pontine reticular formation.

3. *Dopaminergic* pathways from ventral tegmental – rostral mesencephalic nuclear groups. The strongest projection is to the prefrontal cortex, and limbic system.

4. *Cholinergic* pathways from the basal forebrain nucleus of Meynert project widely to cerebral cortex.

5. *GABA-ergic* pathways from basal forebrain, ventral tegmental area and zona incerta to sensory and motor cortex.

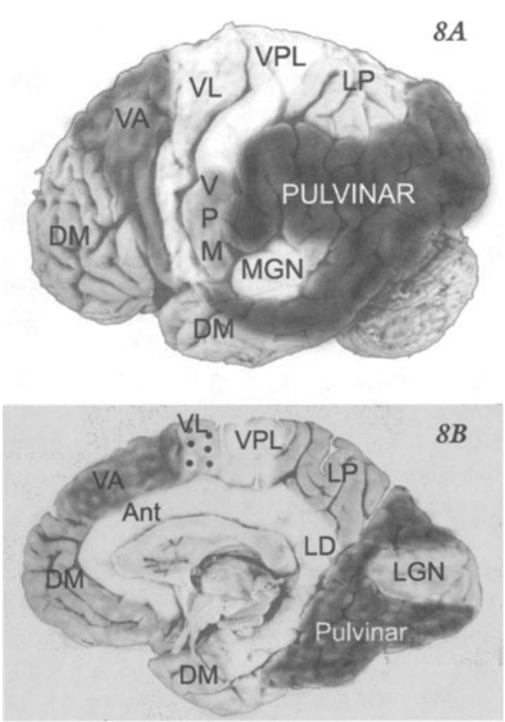

Figure 15-8. Thalamic Projections onto Cerebral Cortex. A. Projections onto Lateral surface of a cerebral hemisphere (B), Projections onto medial surface of cerebral hemisphere

Clinical Considerations.

The thalamus is the final processing station for systems that project to the cerebral cortex; thus it serves an important integrative function. Many sensations are first crudely appreciated at thalamic levels, including pain, touch, taste, and vibration. The discriminative processes associated with these sensations, as well as tactile discrimination, vision, audition, and taste, are elevated to consciousness in the cerebral hemisphere. Glutamate is the principal transmitter in the thalamus.

Thalamic syndrome (of Dejerine). In the human a large lesion in the thalamus results in the thalamic syndrome, causing diminished sensation on the contralateral half of the head and body. (Complete anesthesia results from injury to the ventral posterior lateral nucleus.) Some pain and temperature sensation from the contralateral side of the body may be retained.

The internal capsule is usually involved, producing an upper-motor-neuron lesion of the contralateral limb. The thresholds for pain, temperature, touch, and pressure are usually elevated contralaterally. A mild sensory stimulus now produces exaggerated sensory responses on the affected side and may even cause intractable pain. A change in emotional response may also be noted.

Lesions restricted to the medial thalamic nucleus produce memory and personality disturbances; lesions in the lateral nuclei produce sensory deficits (see Chapter 20).

SUBTHALAMUS (FIG. 15-3)

The subthalamus region is included in the diencephalon, but functionally it is part of the basal ganglia. The subthalamic nucleus, zona incerta, and prerubral field together form the subthalamus. This region is medial to the posterior limb of the internal capsule, lateral to the hypothalamus, and below the thalamus. The ansa lenticularis, subthalamic fasciculus, lenticular fasciculus, and thalamic fasciculus provide input

TABLE 15-4: CORTICAL PROJECTION OF MAJOR THALAMIC NUCLEI

NUCLEUS	CORTICAL PROJECTION	FUNCTION
Anterior & Lateral Dorsal	Cingulate and parahippocampal gyrus	Limbic
Medial Dorsal	Prefrontal & rostral temporal	Limbic
Lateral Geniculate	Calcarine Cortex	Vision
Lateral Posterior	Superior parietal lobule	Sensory Associational
Medial Geniculate	Transverse Temporal of Superior Temporal	Hearing
Pulvinar	Inferior parietal lobule, posterior temporal lobe, and occipital association cortex	Multimodal Associational
Ventral Anterior Associational	Premotor	Motor
Ventral Lateral	Precentral	Motor Cortex
Ventral Posterior	Postcentral	Sensory Cortex

from the globus pallidus to the subthalamus. The zona incerta lies between the thalamus and lenticular fasciculus. The adjacent substantia nigra also projects onto the subthalamus.

The medial portion of the globus pallidus provides the principal input to the subthalamus via the subthalamic fasciculus, which runs through the internal capsule. The motor and premotor cortex also project to this region. The subthalamus projects back to both segments of the globus pallidus, and substantia nigra via the subthalamic fasciculus, and projects to the thalamus and contralateral subthalamus. The glutaminergic cells in the subthalamus form the main excitatory projection from the basal ganglia.

In the human, a lesion in the subthalamus, usually vascular in origin, produces hemiballismus: purposeless, involuntary, violent, flinging movements of the contralateral extremity. These movements persist during wakefulness, but disappear during sleep. This lesion represents underactivity in the indirect pathway in contrast to over activity that produces Parkinsonism. (See Chapter 18).

THE MAJOR SENSORY PATHWAYS OF THE CENTRAL NERVOUS SYSTEM

This discussion will focus on the sensory systems that form the bulk of the afferents to the thalamus. The voluntary motor pathways are discussed in the end of this chapter while the other motor pathways are discussed in Chapters 11, 12, and 17.

Basic Principal of Sensory System: All sensory systems have three neurons:

1st neuron in periphery the dorsal root ganglion or ganglion of cranial nerves V, Vii, IX, or X,

2nd neuron within CNS spinal cord or brain stem; its axon u crosses to the contralateral side, and

3rd order neuron is the final neuron in the sensory systems and its axons reach the cerebral cortex.

Medial Lemniscus--General Somatic Tactile Sensation *(Fig 15-9)*.

The ascending sensory fibers from the body for touch (posterior columns), from the face for touch and pain (trigeminothalamic), and from the viscera for general and special sensation ascend in the medial lemniscus to the dorsal thalamus.

Posterior Columns (Fasciculus Gracilis and Cuneatus).

The posterior columns--the fasciculus gracilis, and the fasciculus cuneatus (Fig. 15-9)--conduct proprioception (position sense), vibration sensation, tactile discrimination, object recognition, deep touch (pressure) awareness, and two-point discrimination from the neck, thorax, abdomen, pelvis, and extremities. The sensory receptors for the system are the Golgi tendon organs, muscle spindles, proprioceptors, tactile discs, and Pacinian corpuscles (deep touch, or pressure). The primary cell body is located in the dorsal root ganglion.

The well-myelinated fibers of this system enter the spinal cord as the medial division of the dorsal root and bifurcate into ascending and descending portions, which enter the dorsal column.

The fasciculus gracilis contains fibers from the sacral, lumbar, and lower thoracic levels, while the fasciculus cuneatus contains fibers from the upper thoracic and cervical levels. Fibers from the sacral levels are the first to enter and lie most medial, followed by lumbar, thoracic, and finally, cervical fibers. The primary axons ascend in the dorsal columns of the spinal cord to the secondary cell body of this system located in the nucleus gracilis and the nucleus cuneatus in the lower medullary levels.

From the secondary cell bodies the fibers cross the midline, join the medial lemniscus, and ascend to the ventral posterior lateral nucleus in the thalamus. From this thalamic nucleus these fibers are projected to the postcentral gyrus (areas 1, 2, 3).

Fibers also descend in the dorsal columns, but their functional significance is unknown.

The fibers responsible for proprioception cross in the medial lemniscus. The fibers for vibration sensation and tactile discrimination ascend bilaterally in the medial lemniscus to the ventral posterior lateral nucleus. Consequently, a unilateral lesion can abolish proprioception, but tactile discrimination and vibration sensation will not be entirely lost.

Clinical Lesions.

Injury to the posterior column appears not to affect pressure sense, but vibration sense, two-point discrimination, and tactile discrimination are diminished or abolished, depending on the extent of the lesion. Interruption of the medial fibers (cervical-hand region) affect the ability to

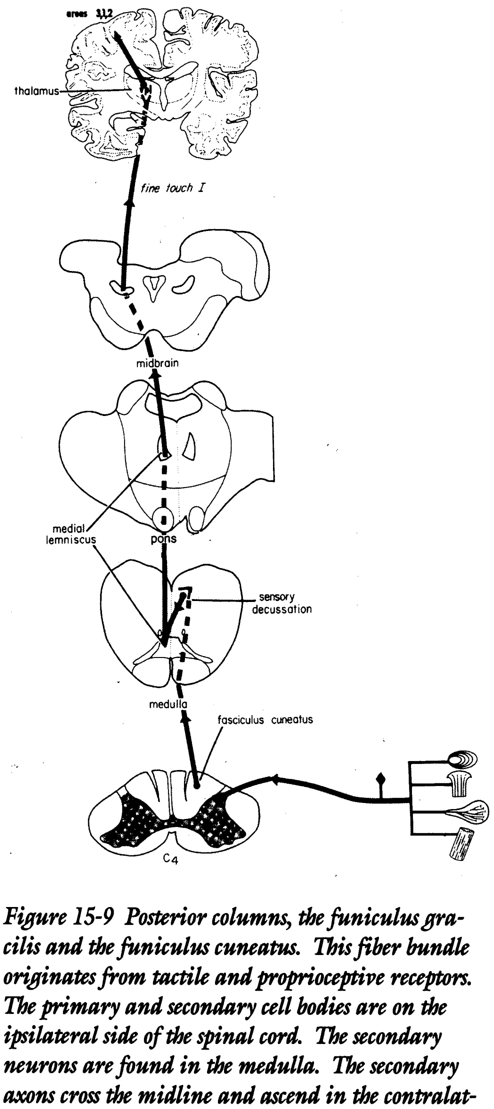

Figure 15-9 Posterior columns, the funiculus gracilis and the funiculus cuneatus. This fiber bundle originates from tactile and proprioceptive receptors. The primary and secondary cell bodies are on the ipsilateral side of the spinal cord. The secondary neurons are found in the medulla. The secondary axons cross the midline and ascend in the contralateral medial lemniscus to the ventral posterior lateral nucleus (VPL) in the thalamus. In the spinal cord the posterior columns are uncrossed and divided into the medial gracile fasciculus (lower extremity) and the lateral cuneate fasciculus (upper extremity). Fibers from the upper extremity form 50 % of the posterior columns with the lower extremity 25% and the remainder from the thorax and abdomen. These fibers cross in the sensory decussation and form the bulk of the medial lemniscus along with trigeminal and other fibers.

recognize differences in the shape and weight of objects placed in the hand is impaired. Since the extremities are more sensitive to these modalities than any other body regions, position sense is impaired more severely in the extremities than elsewhere, and the person has trouble identifying small passive movements of the limbs. Consequently, performance of voluntary acts is impaired and movements are clumsy (sensory ataxia). Lesions in lateral fibers of the posterior column, gracilis, may be devastating due to the interruption of one of the most important sensory mechanisms the ability to detect the sole of the foot. This is a major handicap in walking in dim lighted or a dark room, in driving a car etc.

The discussion of the analysis of tactile information in the cerebral cortex is found in Chapter 21 with several cases also illustrating lesions in this region of the brain.

Tracts Originating from Secondary Trigeminal Nuclei in the Brain Stem (Fig. 15-10). Above all, remember that the primary cells of the trigeminal nerve are located in the trigeminal ganglion in Meckel's cave in the middle cranial fossa.

Proprioception from the Head.

Mesencephalic Nucleus. These unique primary cell bodies are located not only in the trigeminal ganglion but also within the pons and midbrain along the ascending trigeminal rootlets, where they form the mesencephalic nucleus of nerve V. The primary axons project to the motor nucleus of nerve V and the reticular formation. Axons are also projected to the cerebellum and inferior olive.

The origin of the secondary neuron is unclear (but probably the descending nucleus of nerve V). The secondary axons ascend near the medial lemniscus to the ventral posterior medial nucleus of the thalamus.

Pain and Temperature from the Head.

Descending Nucleus of Nerve V. The cell bodies of primary neurons are located in the trigeminal ganglion, and the primary axons are numerous. These fibers enter the pons, lie on the external surface of the descending tract of nerve V, and then terminate in the descending nucleus of nerve V. The ophthalmic fibers descend to C3, the maxillary to C1, and the mandibular to

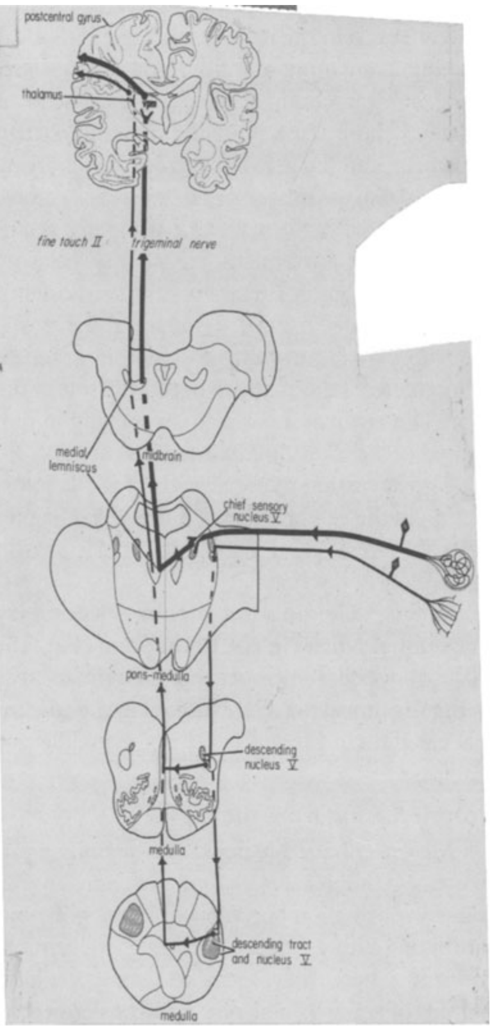

Figure 15-10 Sensory Portion of Trigeminal System. Touch and Pain from the head. This is the largest cranial nerve in the brain stem and has three divisions: Ophthalmic (V1), Maxillary(V2) and Mandibular (V3). Each of these divisions brings in sensation from pain, temperature, touch and pressure receptors in the skin, muscles and sinuses they innervate. The tactile fibers synapse with the chief sensory nucleus in the pons. The Proprioceptive fibers (not shown) enter and ascend through pontine and midbrain levels and synapse on the mesencephalic nucleus of nerve V which then synapses on the motor nucleus of V in the pons for the "jaw jerk". The secondary axons ascend in the medial lemniscus to the ventral posterior medial nucleus (VPM) in the thalamus. The pain fibers cross while the touch fibers run bilateral up to the thalamus, and end in VPM and are then projected onto the lower third of the postcentral gyrus.

the lower medulla. The secondary axons leave the descending nucleus of nerve V and ascend bilaterally in the medial lemniscus to the ventral posterior medial nucleus of the thalamus. The predominant component is crossed.

Tactile Discrimination, Vibration Sensation, and Pressure Sense from the Head,

Chief Nucleus of V. The cell bodies of primary neurons are located in the trigeminal ganglion. The primary axons enter the pons and end on the main sensory nucleus of nerve V, from which the secondary axons ascend contralaterally in the medial lemniscus or ipsilaterally in the dorsal trigeminothalamic tract to the ventral posterior medial nucleus, primarily on the contralateral side of the brain stem.

Lesions in the sensory nuclei cause an absence of sensation on the same side of the head, while lesions of the tracts produce diminished sensation.

Anterolateral Pathways- Spinothalamic and Trigeminothalamic Tract--Pain Pathways *(Fig. 15-10)*

Pain from the Body. Fig 15-11.

Anterolateral Pathway/Spinothalamic. This tract conducts pain and temperature sensation from the neck, thorax, abdomen, pelvis, and extremities. The receptors for pain are the naked free nerve endings, and the corpuscles of Ruffini and of Krause detect warmth and cold. The primary cell bodies are located in the dorsal root ganglion; the axons enter the spinal cord and ascend or descend one segment ipsilaterally before ending on neurons in the dorsal horn lamina 1 to 3. The axons of the secondary cells cross in the anterior commissure of the spinal cord and ascend in the ventrolateral part of the lateral funiculus in the spinal cord and medulla. In the pons they are found at the lateral margin of the medial lemniscus and continue up to the ventral posterior lateral nucleus and the intralaminar nuclei of the dorsal thalamus. The axons in this tract convey information from the contralateral side.

The pain fibers in this tract are arranged segmentally with the most lateroposterior fibers representing the lowest part of the sacral levels of the body, and the more medioanterior fibers representing the upper extremities and neck. The temperature fibers have this same arrangement but are internal to the pain fibers. For surgical relief of pain this tract is located by identifying the denticulate ligament and then sectioning about 1 mm. below the ligament (Fig7-29).

The sharp pain noted with most injuries is associated with the heavily myelinated direct, or spinothalamic, pathway to the ventral posterior lateral nucleus. In addition to the stabbing pain, dull throbbing pain is usually noted; it is carried up more slowly by a multisynaptic pathway, probably via the reticular system, and is called the spinoreticulothalamic pathway.

A unilateral lesion of the spinothalamic tract in the spinal cord produces an almost complete absence of pain (analgesia) and temperature sensation (thermoanesthesia) on the contralateral side. At the upper pontine levels, the lateral spinothalamic tract is usually closely associated with the medial lemniscus. Consequently, a unilateral lesion at these levels diminishes pain and temperature sensation from the opposite side of the body--as well as touch, vibration sensation, and proprioception--.

Anterior Spinothalamic Tract--Light Touch

Light touch awareness from the neck, thorax, pelvis, and extremities is carried up the anterior spinothalamic tract *(Fig 15-11).* The primary neuron is located in the dorsal root ganglion; the secondary neuron is located in the dorsal horn of the same side. The secondary fibers ascend contralaterally in the lateral funiculus, joining the medial lemniscus at the upper pontine levels. Stroking a hairless area of the skin with cotton evokes light touch. Lesions involving this tract produce no definite clinical deficiencies, probably because somewhat similar sensations are also carried in the uncrossed dorsal columns (fine touch, pressure).

Pain and Temperature Sensation from the Head. This information is carried by the descending nucleus and root of nerve V. The primary cell bodies are found in the trigeminal ganglion located in the middle cranial fossa, and the secondary cell bodies originate in the descending nucleus of nerve V. The descending nucleus is very large and extends from pons into medulla and upper cervical spinal cord. This nucleus is divided into three regions pars – oralis

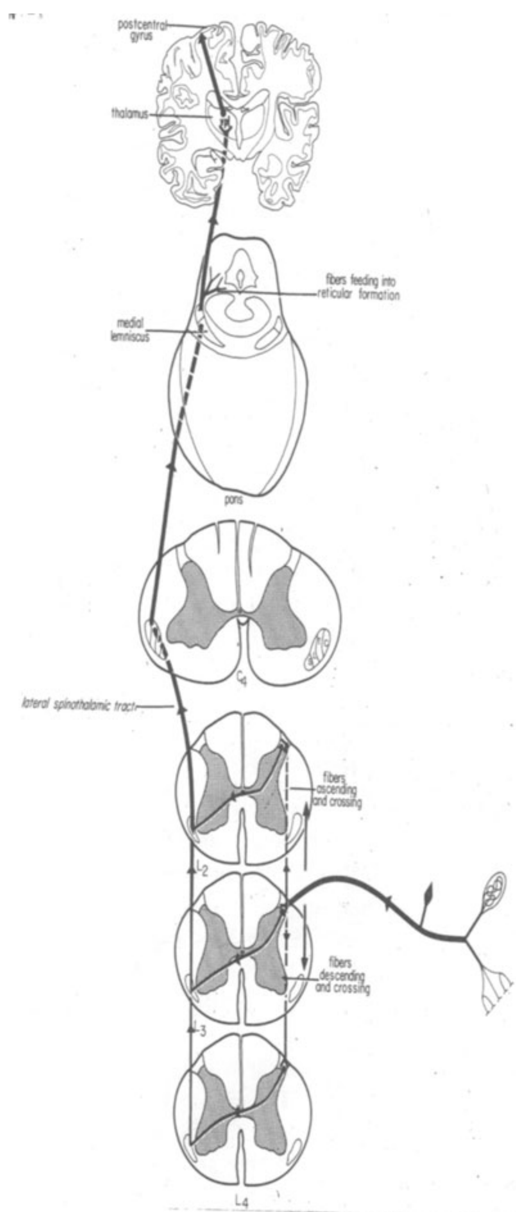

Figure 15-11 Anterolateral pathway-lateral spinothalamic fibers. The Pain Pathway. Originate from pain and temperature receptors in the skin. Primary cell bodies are dorsal root ganglia of the spinal cord. The axons synapse in the dorsal horn, cross within 3 spinal cord segments and form the spinothalamic fibers. These fibers pass into the thalamus. The direct pathway, for localizing the pain on the body, fibers end in VPL which projects onto postcentral gyrus. How one responds to pain comes from the indirect pain pathway that ascends to the dorsomedial thalamic nucleus and is then projected onto the prefrontal gyrus.

(in pons and upper medulla), pars – interpolar (in medulla), and pars – caudalis (in cervical cord). These fibers enter the spinal trigeminal nucleus external to the descending nucleus on the lateral surface of the pons and are somatotopically organized with V3 dorsal, V1 ventral, and V2 intermediate. Fibers of cranial nerves VII, IX and X are dorsal to V3. These fibers descend and end in the spinal trigeminal nucleus with V1 ending in pars caudalis in cervical levels, V2 to interpolar nucleus in medulla, and V3 to pars oralis in upper medulla and pons. The secondary axons ascend contralaterally in the medial lemniscus to the ventral posterior medial nucleus of the thalamus or to the intralaminar nuclei.

Visceral Referred Pain.

Referred pain is caused by painful impulses originating in the viscera that are transmitted by the sympathetic nerves and referred to the periphery of the body. The organ in which the pain is felt belongs to the same sensory dermatome as the visceral structure where it originates as follows: lungs, C8 to T8; heart, C8 to T8; bladder, T1 to T9; testes, T10 to T12; kidneys, T11 to L1, and rectum, S2 to S4.

Unconscious proprioception from the lower extremity, Thorax, Abdomen and Pelvis

This information is carried up to the cerebellum by the anterior and posterior spinocerebellar tracts. The receptors for both tracts are the neuromuscular spindles and the Golgi tendon organs.

Unconscious Proprioception from the Lower Extremity, Thorax, Abdomen, and Pelvis. This information is carried up to the cerebellum by the anterior and posterior spinocerebellar tracts.

Unconscious Proprioception from the Upper Extremity and Neck and Head.

Cuneocerebellar Pathway. The primary neurons are found in the dorsal root ganglion at cervical levels and in the trigeminal proprioceptive fibers. Their axons ascend in the dorsal columns and end in the external cuneate nuclei (external to the cuneate nucleus) in the lower medullary levels. The secondary axons ascend bilaterally with the posterior spinocerebellar tract and enter the cerebellum primarily uncrossed.

Cerebellar Tracts--Unconscious Proprioception See chapter 21.

The cerebellar cortex must have proprioceptive information to insure proper muscle tone and coordination. Fibers carrying this information run to the cerebellum in the following pathways: posterior spinocerebellar, anterior spinocerebellar, cuneocerebellar.

Posterior Spinocerebellar Tract *(Fig. 15-12).* The primary neuron is located in

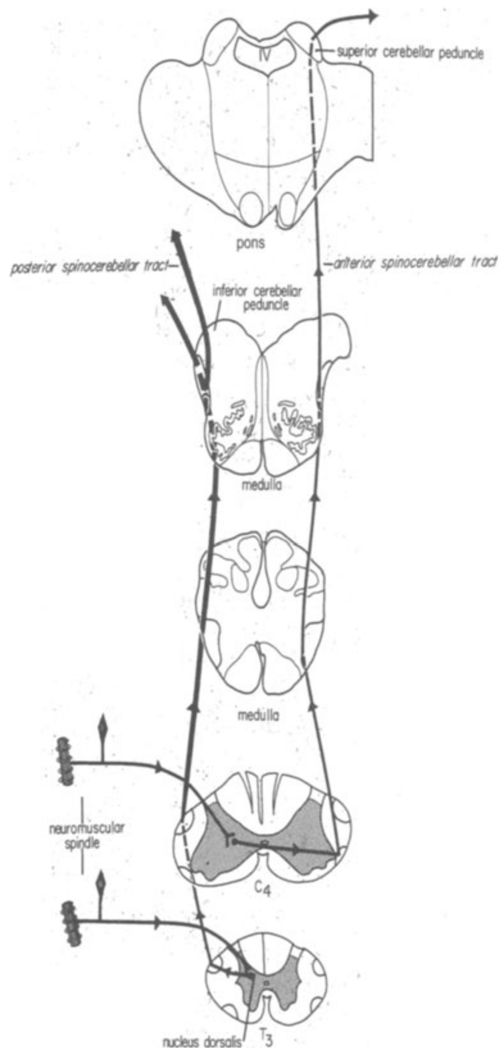

Figure 15-12. Anterior and posterior Spinocerebellar Pathways. -Unconscious proprioception to the cerebellum. These tracts carry information from Proprioceptive receptors in the body into the cerebellum with the anterior pathway crossed and the posterior uncrossed.

the dorsal root ganglion; the secondary neuron is located in Clarke's column in the dorsal horn at levels C8 to L3 of the cord. The secondary axons ascend uncrossed in the lateral funiculus, enter the cerebellum via the inferior cerebellar peduncle, and terminate in the ipsilateral vermis (midline portion of the cerebellum).

Anterior Spinocerebellar Tract (Fig. 15-12). The primary neuron is in the dorsal root ganglion, while the secondary neuron is in cells at the margin of the dorsal horn that are scattered throughout the spinal cord, especially in the lumbar levels. The secondary axon crosses the midline and ascends anterior to the posterior spinocerebellar tract in the lateral funiculus and medulla; it enters the cerebellum via the superior cerebellar peduncle and terminates in the same parts of the cerebellar vermis as the posterior spinocerebellar tract except it is located on the contralateral side.

The receptors for both tracts are the neuromuscular spindles and Golgi tendon organs.

Cerebellar Peduncles (see Chapter 20). The cerebellum is interconnected to the brain stem by three major fiber bundles, or brachium: the superior cerebellar, middle cerebellar, and inferior cerebellar peduncles.

The axons in the *superior cerebellar peduncle* (brachium conjunctivum) are primarily efferent and ascending axons originating in the deep cerebellar nuclei - dentate, emboliform,

These fibers cross in the tegmentum of the lower midbrain (decussation of the superior cerebellar peduncle) with some fibers ending on the red nucleus and oculomotor complex. However, the majority of the fibers in the superior cerebellar peduncle distribute to the motor nuclei of the thalamus - ventral lateral and ventral anterior nuclei. This cerebellar projection to the motor cortex permits the well-controlled volitional acts of the corticospinal and corticobulbar systems. The ventral spinocerebellar fibers enter the cerebellum through the superior cerebellar peduncle.

The *middle cerebellar peduncle* (brachium pontis) is the largest cerebellar peduncle and is purely afferent (Fig. 15-12). The largest group of descending fibers from the cerebral hemispheres is directed upon the pontine gray. These fibers form the bulk of the cerebral peduncle and descend from all cortical lobes and the cingulate and insular gyrus, with the largest group of fibers coming from the somatosensory strip and premotor cortex. These corticopontine fibers synapse upon the pontine gray and then pass into the contralateral cerebellar hemisphere. Lesions in these fibers systems do not cause any clinical deficit although these fibers must be important in all fine movements.

The corticopontine fibers end on the pontine nuclei. The axons from the pontine nuclei are crossed and constitute part of the mossy-fiber input to the granule cells.

The *inferior cerebellar peduncle* (restiform body) connects the brain stem and spinal cord with the cerebellum (Fig. 15-12). The climbing fibers from the inferior olive enter this peduncle and extend to the Purkinje cells in the deep cerebellar nuclei. The fibers from the vestibular nuclei, reticular formation, and trigeminal nuclei, as well as the dorsal spinocerebellar fibers, enter through this peduncle. Many of these fibers contribute to the mossy-fiber input to the cerebellum. The aminergic fibers from the raphe and locus ceruleus also enter the cerebellum through the inferior cerebellar peduncle. There is a major cerebellar projection onto the reticular formation of the pons and medulla and onto the vestibular nuclei from the fastigial nucleus, as well as a strong cerebellar input onto the vestibular nuclei from the flocculonodular lobe.

SPECIAL SENSORY CRANIAL NERVE VIII

Visual Pathway. Discussed in Chapter 21 on Vision.

The inner ear that contains the receptors for the auditory and vestibular systems and their central projections are discussed in the Special Sensory Section on the CD that also includes the Chapter on Vision.

CN VIII - Auditory Pathway. The auditory nerve, Cranial Nerve VIII, terminates in the dorsal and ventral cochlear nuclei in the medulla. Each sound has a specific location on the cochlea. The termination is in a tonotopic pattern in each nucleus with the low frequency fibers terminating ventrally and the high frequency fibers dorsally creating a series of frequency sensitive layers. The frequency of sounds is from 100 - 15,000Hz.

The dorsal cochlear nucleus projects contralaterally through the lateral lemniscus to the inferior colliculus while the ventral cochlear nucleus projects bilaterally to the medial superior olivary nucleus and ipsilateral lateral superior olivary nucleus. Frequencies above 2000 Hz are recorded in the lateral superior olivary nucleus. The lateral superior olive projects to the contralateral inferior colliculus while the medial superior olivary nucleus projects ipsilaterally to inferior colliculus, medial geniculate and auditory cortex.

Cortical Projection. The laminated ventral medial geniculate projects onto the primary auditory cortex area 41 while the dorsal medial geniculate projects onto auditory association areas 42.

CN VIII - Vestibular Pathway (These fibers should be considered part of the proprioceptive system).

The vestibular fibers originated from two ganglia the superior and inferior ganglia of Scarpa. There are 4 major vestibular nuclei: superior (SVN), lateral (LVN), medial (MVN) and inferior (IVN). Trunk and limb somatosensory pathways send information to LVN, MVN and IVN. Visual information also indirectly reaches these same nuclei. The semicircular input reaches SVN, MVN, and LVN. The utricle projects mainly to LVN, the saccule to IVN. The fastigial nucleus of the cerebellum is excitatory to the vestibular nuclei while the cerebellar cortex is inhibitory. The vestibular nuclei project to deep layers of the superior colliculus adjacent to projections from cervical proprioceptive endings.

Cortical Projection. From the LVN there is a small contralateral input to ventroposterior and medial magnocellular of MGN. Ventroposterior projects to SI arm region of 3a, while the MGN projects to area 5 and the neck region of area 2. Stimulation of either of these cortical regions produces vestibular sensations. The cortical neurons respond to both vestibular and proprioceptive stimuli from neck trunk and proximal joints and the response are excitatory for one rotation in one direction and inhibitory in the other.

Taste and General Sensation from the Viscera

General sensation from the gastrointestinal system (cranial nerve X) and from the taste buds on the tongue (cranial nerves, VII, IX, and X) enters the brain stem to terminate on the nucleus solitarius in the medulla. Fibers ascend primarily uncrossed either in the central tegmental pathway or in the medial lemniscus to reach basomedial portion of ventral posterior medial (VPM) nucleus in the dorsal thalamus. Many of the gustatory fibers terminate in the ipsilateral parabrachial nucleus before reaching the ventrobasal portion of VPM nucleus. The cortical region for taste is in the parietal lobe in the upper banks of the lateral sulcus.

MAJOR VOLUNTARY MOTOR PATHWAYS

In the older literature the motor pathways were divided into pyramidal (corticospinal and corticonuclear) and extrapyramidal (rubrospinal, tectospinal, and so on). These terms are no longer used, and each pathway is now usually described in terms of its function.

Basic Principal of Motor System. The motor system consists of two portions: an upper and lower motor neuron. The portion originating in the gray matter of the motor sensory strip of the cerebral cortex is called upper motor neurons. The pathway from the upper motor neurons, corticospinal or corticonuclear, descends and crosses over to innervate the lower motor neurons in the brain stem or spinal cord.

The axons of the upper motor neurons either synapse on interneurons or end directly on the lower motor neurons. The axons of the lower motor neurons leave the central nervous system and form the motor division of the peripheral nervous system.

CORTICOSPINAL TRACTS--VOLUNTARY CONTROL OF THE LIMBS, THORAX, AND ABDOMEN. *(Fig. 15-13)*

This tract innervates the motor neurons that control the skeletal muscles in the neck, thorax, abdomen, pelvis, and the extremities. It is essential for accurate voluntary movements and is the only direct tract from the cortex to the spinal motor neurons.

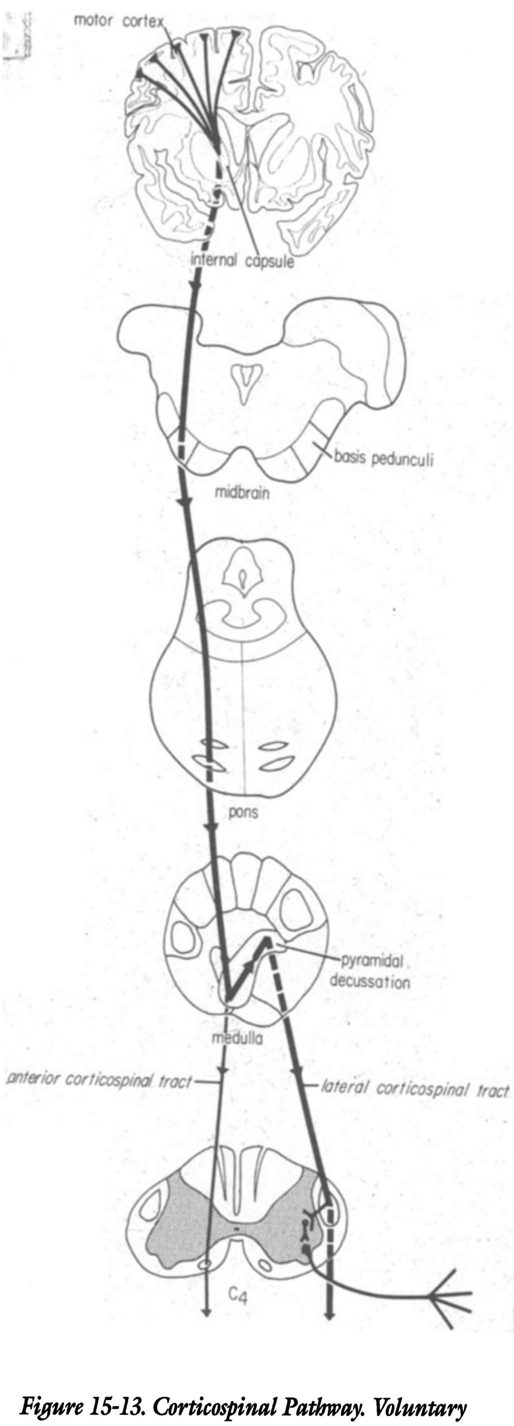

Figure 15-13. Corticospinal Pathway. Voluntary Movement of the Muscles in the upper and lower extremities, thorax and abdomen.

This system originates from the pyramidal cells and giant cells of Betz in the upper two-thirds of the precentral gyrus, area 4, and to a lesser degree from area 6 and parts of the frontal, parietal, temporal, and cingulate cortices. The fibers pass through the genu of the internal capsule into the middle third of the cerebral peduncles and enter the pons, where they are broken into many fascicles and are covered by pontine gray and white matter. In the medulla, the fibers are again united and are found on the anterior medial surface of the brain stem in the medullary pyramids.

About 75 to 90% of the corticospinal tract fibers cross at the medullospinal junction and are thereafter found in the lateral funiculus of the spinal cord. (The majority of fibers from the dominant hemisphere cross at the medullospinal junction.) Some corticospinal fibers remain uncrossed in the anterior funiculus but will slowly cross at cervical levels. About 50% of the corticospinal fibers end at the cervical levels--about 30% go to the lumbosacral levels, and the remainder to the thoracic levels.

Most of the corticospinal fibers end on internuncial neurons in laminae 7 and 8 of the spinal cord, but in regions in the spinal cord where the digits are represented (in the cervical and lumbosacral enlargements) the corticospinal fibers sometimes end directly on the motor horn cells. The internuncial neurons are located in lamina 7 of the spinal cord. Lesions in the corticospinal tract produce contralateral upper motor neuron symptoms, while lesions in the spinal motor neurons or rootlets cause lower motor neuron symptoms.

CORTICONUCLEAR SYSTEM--VOLUNTARY CONTROL OF THE MUSCLES CONTROLLED BY CRANIAL NERVES V, VII, AND IX TO XII *(Figs. 15-14)*

This system distributes to the motor nuclei of the cranial nerves V, VII, IX, X, XI, and XII and provides voluntary and involuntary control of the muscles and glands innervated by these nerves. In the older literature this pathway was called corticobulbar because the medulla and pons containing these nuclei are collectively called the bulb. We prefer the term corticonuclear because it makes the student realize the key role of the cranial nerve nuclei in movement. These fibers are found anterior to the corticospinal fibers in the genu of the internal capsule and medial to the corticospinal tract in the cerebral peduncle, pons, and medullary pyramids.

The fibers supplying the cranial nerves have the following cortical origin:

1. Muscles of facial expression (motor nerve VII), mastication (motor nerve V), and deglutition (ambiguous nuclei of nerves IX and X) originate from pyramidal cells in the inferior part of the precentral gyrus, area 4.

2. Muscles in the larynx are controlled from the inferior frontal gyrus and from the frontal operculum (the posterior part of the pars triangularis, area 44). It appears that many corticonuclear axons end on interneurons and not directly on the motor neuron of the cranial nerve.

3. The cortical innervation of the cranial nerves is bilateral, with the exception of the lower facial muscles, which are innervated by the contralateral cortex. Consequently unilateral lesions in the corticonuclear system produce only weakness and not paralysis. Paralysis results only from bilateral lesions in the corticonuclear system.

4. Lower motor neuron lesions of motor cranial nerves. A lesion of the motor nucleus or rootlet produces a lower motor neuron syndrome with paralysis, muscle atrophy and decreased reflexes.

Supranuclear lesions produce upper motor neuron symptoms. Associated with bilateral lesions of the corticonuclear system is pseudobulbar palsy with bilateral UMN signs and inappropriate behavioral. This probably represents the release of cortical control via the corticonuclear innervation of the muscles controlled by the cranial nerves. Limbic control to these nuclei takes over, via descending autonomic pathways, and the emotional state is undamped by the frontal lobes

CORTICOMESENCEPHALIC SYSTEM--VOLUNTARY CONTROL OF MUSCLES ASSOCIATED WITH EYE MOVEMENTS--CRANIAL NERVES III, IV, AND VI.

The fibers controlling eye movements originate from the frontal eye fields in the caudal part of the middle frontal gyrus and the adjacent inferior frontal gyrus (area 8). At upper midbrain levels, fibers to cranial nerves III and IV leave the cerebral peduncles and take a descending path through the tegmentum, usually in the medial lemniscus (corticomesencephalic tract). Fibers to cranial nerve VI also descend in this way to the parabducens and parapontine reticular nuclei of

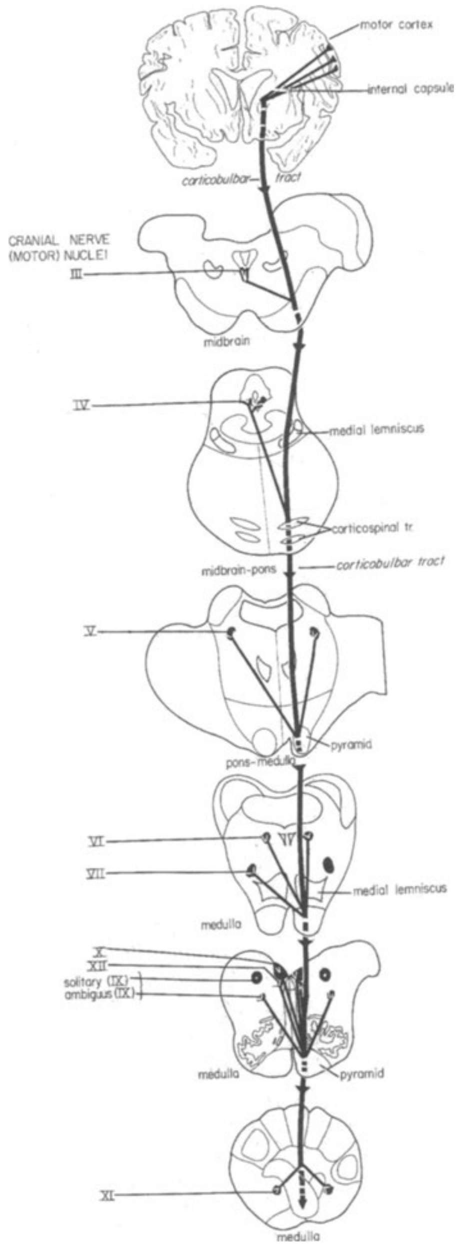

Figure 15-14. Corticobulbar/Corticonuclear Pathway. Voluntary Movements of the muscles associated with Cranial Nerves V, VII, and IX, X, XI, XII. Control of the cranial nerves that move the muscles (III, IV & VI) of the eyes is through the Corticomesencephalic pathway

the pons, which coordinate movements under the control of cranial nerves III and VI ascending through the medial longitudinal fasciculus.

The table that follows, Table 15-5, lists the Major Sensory and Motor Pathways in the human central nervous system

TABLE 15-5. MAJOR SUBCORTICAL TRACTS WITHIN THE BRAIN STEM AND DIENCEPHALON

Pathway	Function
Sensory Pathways	Functions
Spinothalamics and Trigeminothalamics	Pain and temperature from body, head and neck
Solitary tract	Taste and general sensation from the viscera
Cerebellar Peduncles: Superior (Cerebellum-Cerebrum) Middle (Cerebrum-Cerebellum) Inferior (Cerebellum with brain stem and spinal cord & CN VIII)	Unconscious sensory and motor
Optic Pathway - from retina via lateral geniculate to calcarine cortex (Chapter 21).	Vision & light reflexes
Auditory Pathway – cochlear nuclei via lateral lemniscus to inferior colliculus, brachium of inferior colliculus to medial geniculate and to auditory cortex, (Chapter 11 & Inner Ear- Special Senses on CD).	Auditory
Vestibular Pathway (Part of Proprioceptive Pathway)- lateral vestibular nucleus to Ventral posterior and MGN then to postcentral gyrus. (Chapter 11 & inner ear –Special Senses on CD)	Proprioceptive
Motor Pathways	Functions
Corticospinal.	Voluntary control of muscles in limbs thorax and abdomen
Corticonuclear	Voluntary control of: Facial expression by innervation of cranial nerves V, VII, IX-XII. Larynx by innervation of cranial nerves
Corticomesencephalic	Voluntary control of eye movements by innervation of cranial nerves III, IV and VI.
Rubrospinal, rubronuclear, tectospinal & tectonuclear	Backup to voluntary motor system
Reticular	Limbic (emotional)
Medial Longitudinal Fasciculus	Coordinate eye movements in brain stem via cranial nerves III, IV & VI
Monamine Containing: Norepinephrine, dopaminergic, serotonergic	Set tone in motor system and effect limbic system.
Descending sympathetics & parasympathetics	Autonomic functions