6 Cerebellum and Its Connections

CHAPTER OBJECTIVES

- To review the structure and functions of the cerebellum
- To describe the afferent and efferent connections of the cerebellum within the central nervous system

A 56-year-old woman is examined by a neurologist for a variety of complaints, including an irregular swaying gait and a tendency to drift to the right when walking. Her family recently noticed that she has difficulty in keeping her balance when standing still, and she finds that standing with her feet apart helps her keep her balance.

On examination, she has diminished tone of the muscles of her right upper limb, as seen when the elbow and wrist joints are passively flexed and extended. Similar evidence is found in the right lower limb. When asked to stretch out her arms in front of her and hold them in position, she demonstrates obvious signs of right-sided tremor. When asked to touch the tip of her nose with the left index finger, she performs the movement without any difficulty, but when she repeats the movement with her right index finger, she either misses her nose or hits it due to the irregularly contracting muscles. When she is asked to quickly pronate and supinate the forearms, the movements are normal on the left side but jerky and slow on the right side. A mild papilledema of both eyes is found. No other abnormal signs are seen.

The right-sided hypotonia, static tremor, and intention tremor associated with voluntary movements, right-sided dysdiadochokinesia, and the history are characteristic of right-sided cerebellar disease. A computed tomography scan reveals a tumor in the right cerebellar hemisphere.

Understanding the structure and the nervous connections of the cerebellum and, in particular, knowing that the right cerebellar hemisphere influences voluntary muscle tone on the same side of the body enable the neurologist to make an accurate diagnosis and institute treatment.

The cerebellum plays a very important role in the control of posture and voluntary movements. It unconsciously influences the smooth contraction of voluntary muscles and carefully coordinates their actions, together with the relaxation of their antagonists. Students should commit the functions of the connections of the cerebellum to the remainder of the central nervous system (CNS) to memory, as this will greatly assist in the retention of the material. In this chapter, great emphasis is placed on the fact that each cerebellar hemisphere controls muscular movements on the same side of the body and that the cerebellum has no direct pathway to the lower motor neurons but exerts its control via the cerebral cortex and the brainstem.

GROSS APPEARANCE

The cerebellum is situated in the posterior cranial fossa and is covered superiorly by the tentorium cerebelli. It is the largest part of the hindbrain and lies posterior to the fourth ventricle, the pons, and the medulla oblongata (Fig. 6-1). The cerebellum is somewhat ovoid in shape and constricted in its median part. It consists of two **cerebellar hemispheres** joined by a narrow median **vermis**. The cerebellum is connected to the posterior aspect of the brainstem by three symmetrical bundles of nerve fibers called the **superior**, **middle**, and **inferior cerebellar peduncles** (see Figures 1-12 and 5-18).

The cerebellum is divided into three main lobes: the **anterior lobe**, the **middle lobe**, and the **flocculonodular lobe**. The **anterior lobe** may be seen on the superior surface of the cerebellum and is separated from the middle lobe by a wide V-shaped fissure called the **primary fissure** (Figs. 6-2 and 6-3). The **middle lobe** (sometimes called the posterior lobe), which is the largest part of the cerebellum, is situated between the primary and **uvulonodular fissures**. The **flocculonodular lobe** is situated posterior to the uvulonodular fissure (Fig. 6-3). A deep **horizontal fissure** that is found along the margin of the cerebellum separates the superior from the inferior surfaces but has

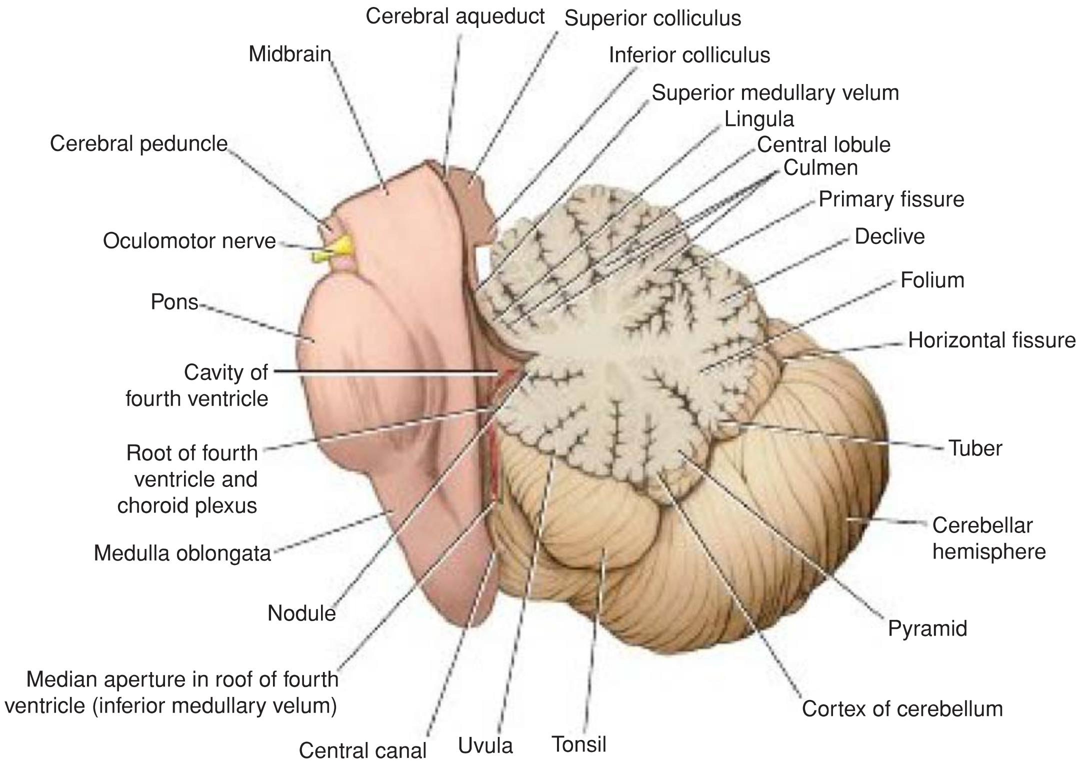

Figure 6-1 Sagittal section through the brainstem and the vermis of the cerebellum.

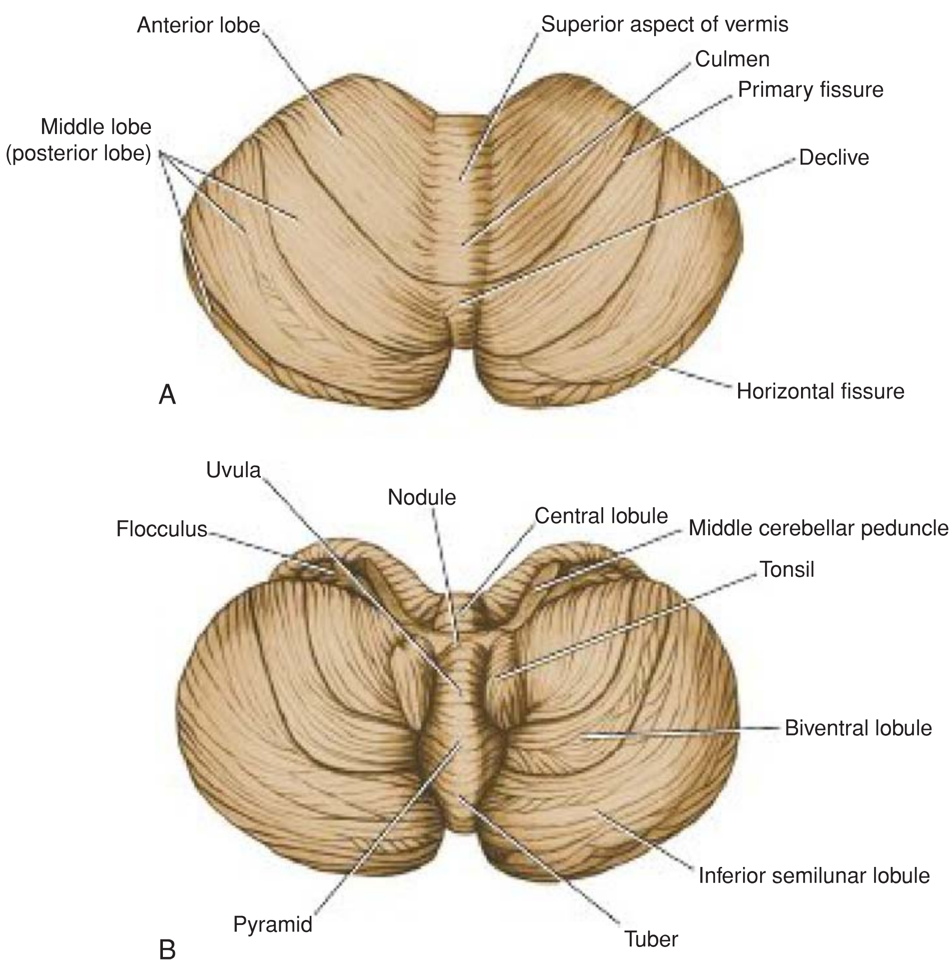

Figure 6-2 The cerebellum. **A:** Superior view. **B:** Inferior view.

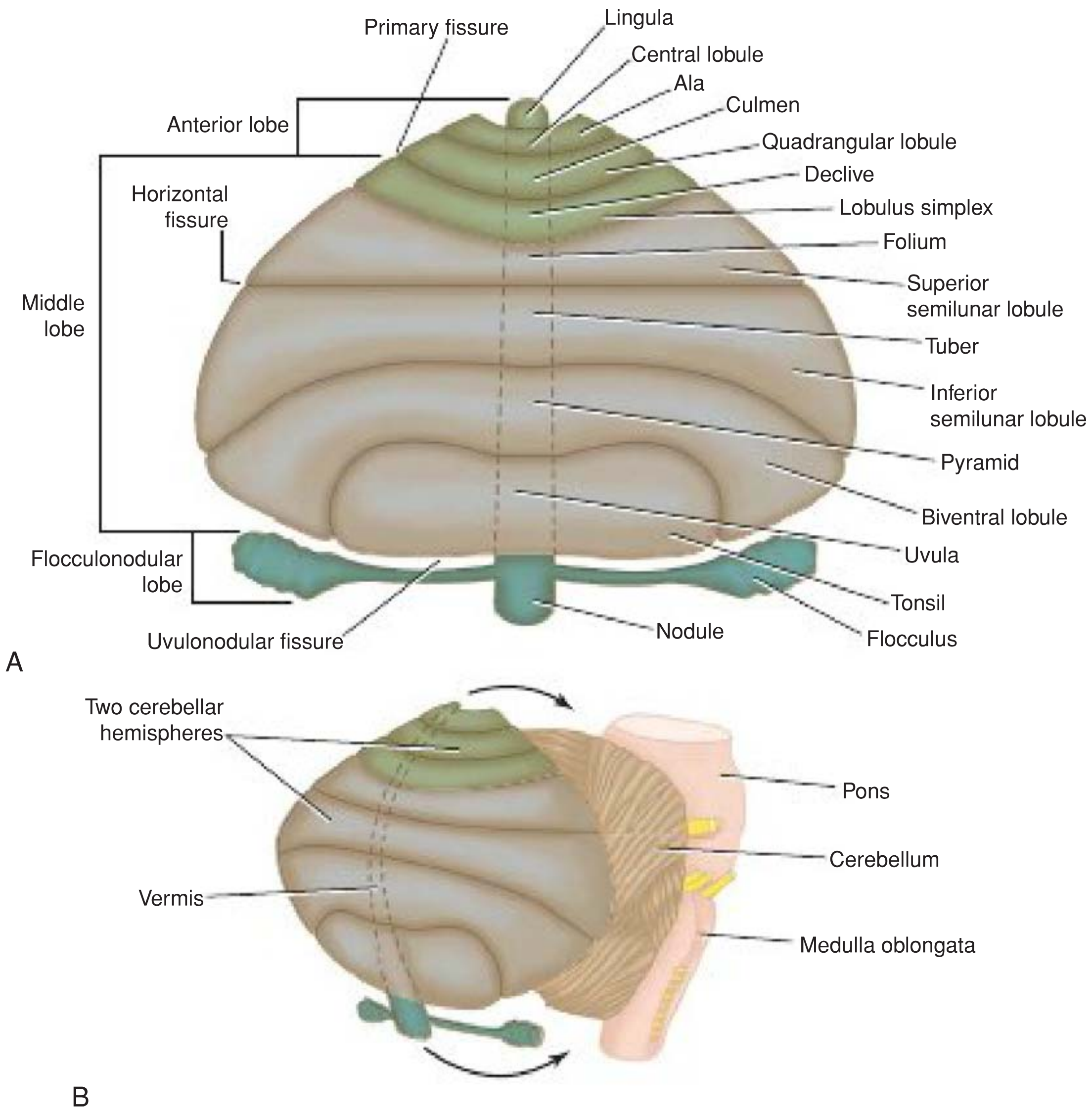

Figure 6-3 **A:** Flattened view of the cerebellar cortex showing the main cerebellar lobes, lobules, and fissures. **B:** Relationship between the diagram in (**A**) and the cerebellum.

no morphologic or functional significance (Figs. 6-2 and 6-3).

STRUCTURES

The cerebellum is composed of an outer covering of gray matter called the **cortex** and inner white matter. Embedded in the white matter of each hemisphere are three masses of gray matter forming the **intracerebellar nuclei**.

Cerebellar Cortex

The cerebellar cortex can be regarded as a large sheet with folds lying in the coronal or transverse plane. Each fold or folium contains a core of white matter covered superficially by gray matter (see Fig. 6-1).

A section made through the cerebellum parallel with the median plane divides the folia at right angles, and the cut surface has a branched appearance, called the **arbor vitae**.

The gray matter of the cortex throughout its extent has a uniform structure. It may be divided into three layers: (1) an external layer, the **molecular layer**; (2) a middle layer, the **Purkinje cell layer**; and (3) an internal layer, the **granular layer** (Figs. 6-4 and 6-5).

Molecular Layer

The molecular layer contains two types of neurons: the outer **stellate cell** and the inner **basket cell** (see Fig. 6-4). These neurons are scattered among dendritic arborizations and numerous thin axons that run parallel to the long axis of the folia. Neuroglial cells are found between these structures.

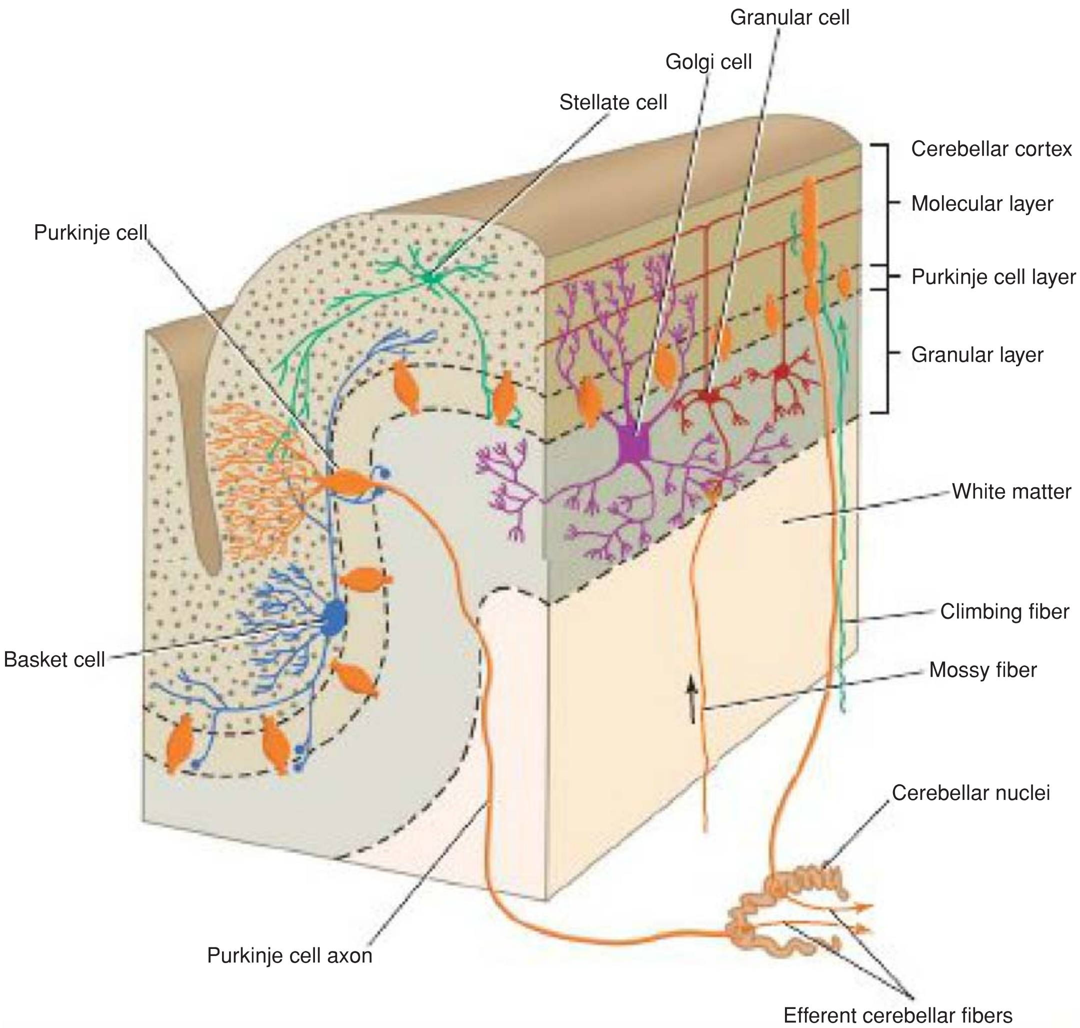

Figure 6-4 Cellular organization of the cerebellar cortex. Note the afferent and efferent fibers.

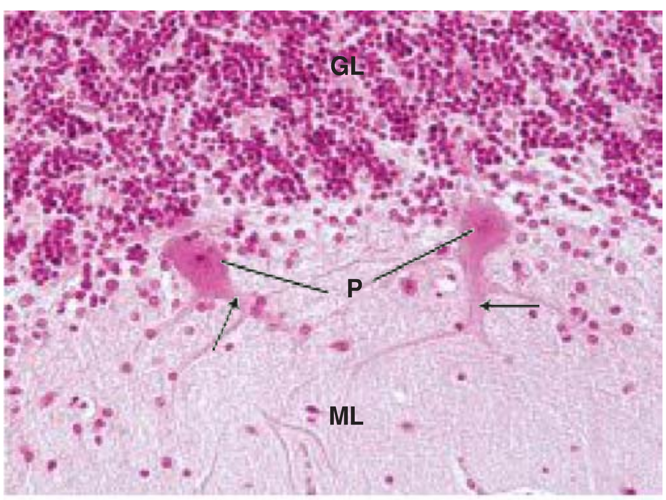

Figure 6-5 Light micrograph of the cerebellum (×132). Observe the Purkinje cells (P) with their dendritic trees (arrows) protruding into the molecular layer (ML). The heavily populated and deeply stained region is the granular layer (GL) of the cerebellum. (From Gartner, L. P. [2018]. *Color atlas and text of histology* [7th ed.]. Baltimore, MD: Wolters Kluwer.)

Purkinje Cell Layer

The Purkinje cells are large Golgi type I neurons. They are flask shaped and are arranged in a single layer (see Figs. 6-4 and 6-5). In a plane transverse to the folium, the dendrites of these cells are seen to pass into the molecular layer, where they undergo profuse branching. The primary and secondary branches are smooth, and subsequent branches are covered by short, thick **dendritic spines**. It has been shown that the spines form synaptic contacts with the parallel fibers derived from the granule cell axons.

At the base of the Purkinje cell, the axon arises and passes through the granular layer to enter the white matter. On entering the white matter, the axon acquires a myelin sheath, and it terminates by synapsing with cells of one of the intracerebellar nuclei. Collateral branches of the Purkinje axon make synaptic contacts with the dendrites of basket and stellate cells of the granular layer in the same area or in distant folia. A few of the Purkinje cell axons pass directly to end in the vestibular nuclei of the brainstem.

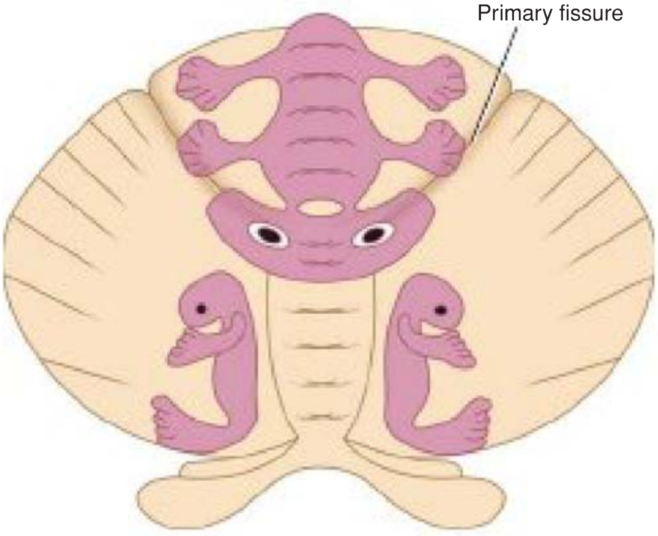

Figure 6-6 Somatosensory projection areas in the cerebellar cortex.

Granular Layer

The granular layer is packed with small cells with densely staining nuclei and scanty cytoplasm. Each cell gives rise to four or five dendrites, which make claw-like endings and have synaptic contact with mossy fiber input (see Fig. 6-4). The axon of each granule cell passes into the molecular layer, where it bifurcates at a T junction, the branches running parallel to the long axis of the cerebellar folium (see Fig. 6-4). These fibers, known as **parallel fibers**, run at right angles to the dendritic processes of the Purkinje cells. Most of the parallel fibers make synaptic contacts with the spinous processes of the dendrites of the Purkinje cells. Neuroglial cells are found throughout this layer. Scattered throughout the granular layer are Golgi cells. Their dendrites ramify in the molecular layer, and their axons terminate by splitting up into branches that synapse with the dendrites of the granular cells (see Fig. 6-5).

Functional Areas

Clinical observations by neurologists and neurosurgeons and the experimental use of positron emission tomography have shown that the cerebellar cortex can be divided into three functional areas.

The cortex of the vermis influences the movements of the long axis of the body, namely, the neck, the shoulders, the thorax, the abdomen, and the hips (Fig. 6-6). Immediately lateral to the vermis is a so-called intermediate zone of the cerebellar hemisphere. This area has been shown to control the muscles of the distal parts of the limbs, especially the hands and feet. The lateral zone of each cerebellar hemisphere appears to be concerned with the planning of sequential movements of the entire body and is involved with the conscious assessment of movement errors.

Intracerebellar Nuclei

Four masses of gray matter are embedded in the white matter of the cerebellum on each side of the midline (Fig. 6-7). From lateral to medial, these nuclei are the **dentate**, the **emboliform**, the **globose**, and the **fastigial**.

The **dentate nucleus** is the largest of the cerebellar nuclei. It has the shape of a crumpled bag with the opening facing medially. The interior of the bag is filled with white matter made up of efferent fibers that leaves the nucleus through the opening to form a large part of the superior cerebellar peduncle.

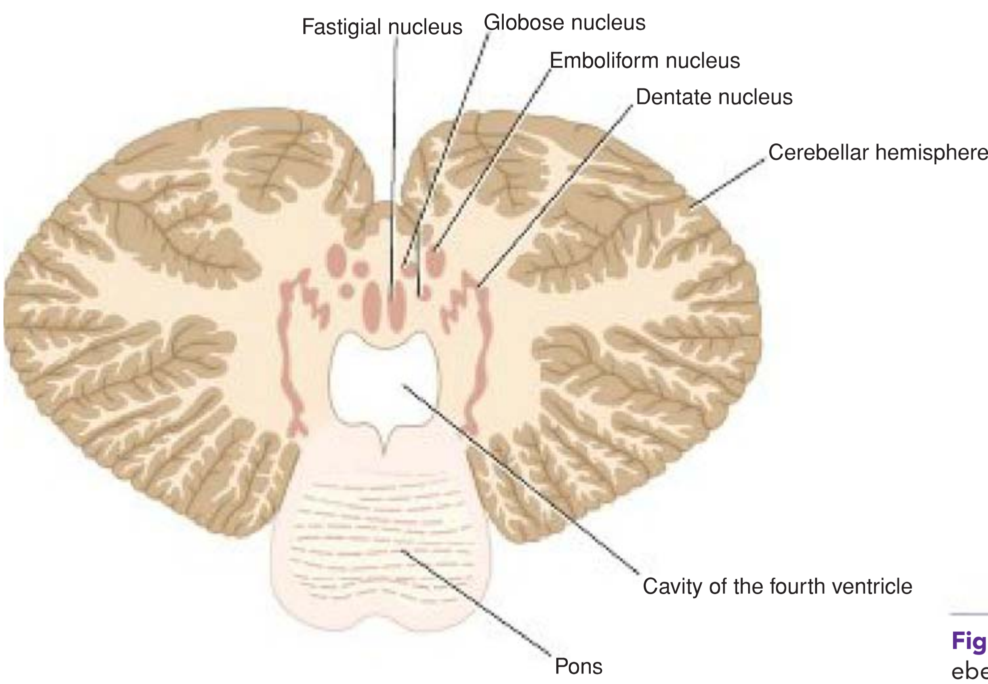

Figure 6-7 Position of the intracerebellar nuclei.

The **emboliform nucleus** is ovoid and is situated medial to the dentate nucleus, partially covering its hilus.

The **globose nucleus** consists of one or more rounded cell groups that lie medial to the emboliform nucleus.

The **fastigial nucleus** lies near the midline in the vermis and close to the roof of the fourth ventricle; it is larger than the globose nucleus.

The intracerebellar nuclei are composed of large, multipolar neurons with simple branching dendrites. The axons form the cerebellar outflow in the superior and inferior cerebellar peduncles.

White Matter

There is a small amount of white matter in the vermis; it closely resembles the trunk and branches of a tree and thus is termed the **arbor vitae** (see Fig. 6-1). There is a large amount of white matter in each cerebellar hemisphere.

The white matter is made up of three groups of fibers: (1) intrinsic, (2) afferent, and (3) efferent.

The **intrinsic fibers** do not leave the cerebellum but connect different regions of the organ. Some interconnect folia of the cerebellar cortex and vermis on the same side; others connect the two cerebellar hemispheres together.

The **afferent fibers** form the greater part of the white matter and proceed to the cerebellar cortex. They enter the cerebellum mainly through the inferior and middle cerebellar peduncles.

The **efferent fibers** constitute the output of the cerebellum and commence as the axons of the Purkinje cells of the cerebellar cortex. The great majority of the Purkinje cell axons pass to and synapse with the neurons of the cerebellar nuclei (fastigial, globose, emboliform, and dentate). The axons of the neurons then leave the cerebellum. A few Purkinje cell axons in the flocculonodular lobe and in parts of the vermis bypass the cerebellar nuclei and leave the cerebellum without synapsing.

Fibers from the dentate, emboliform, and globose nuclei leave the cerebellum through the superior cerebellar peduncle. Fibers from the fastigial nucleus leave through the inferior cerebellar peduncle.

CEREBELLAR CORTICAL MECHANISMS

As a result of extensive cytologic and physiologic research, certain basic mechanisms have been attributed to the cerebellar cortex. The climbing and the mossy fibers constitute the two main lines of input to the cortex and are **excitatory** to the Purkinje cells (Fig. 6-8).

The **climbing fibers** are the terminal fibers of the olivocerebellar tracts. They are so named because they ascend through the layers of the cortex like a

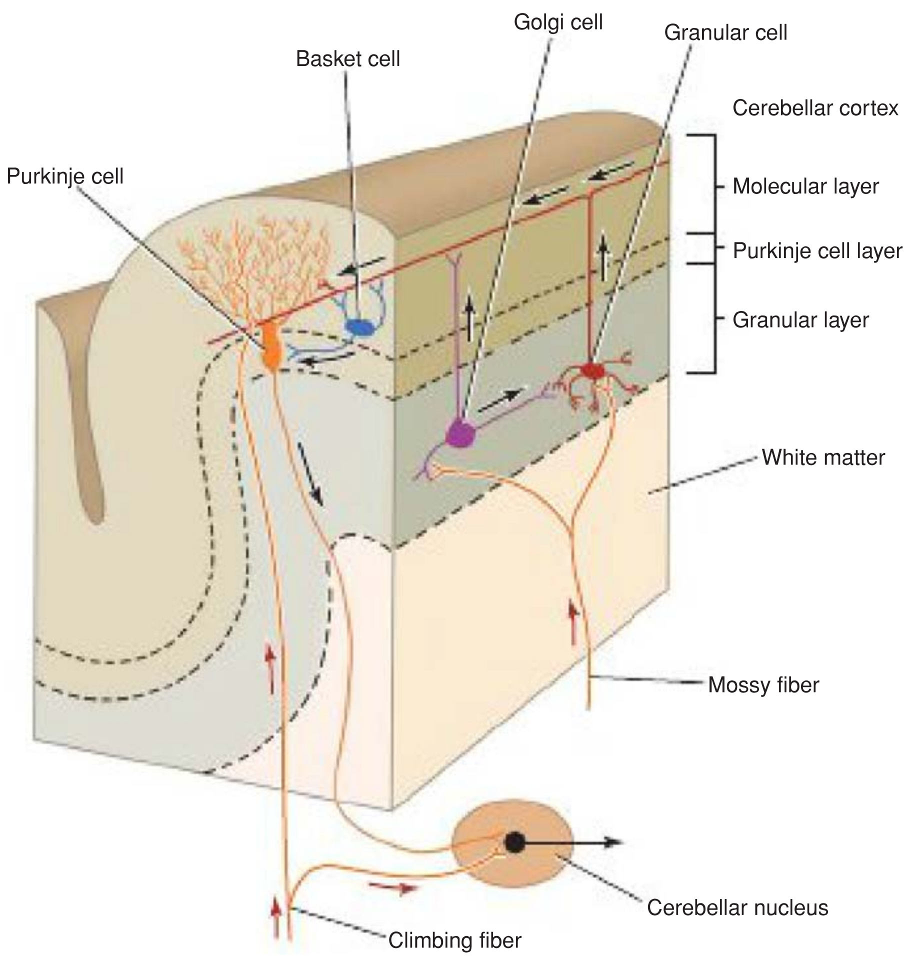

Figure 6-8 Functional organization of the cerebellar cortex. The *arrows* indicate the direction taken by the nervous impulses. The red *arrows* indicate information entering the cerebellum.

vine on a tree. They pass through the granular layer of the cortex and terminate in the molecular layer by dividing repeatedly. Each climbing fiber wraps around and makes a large number of synaptic contacts with the dendrites of a Purkinje cell. A **single** Purkinje neuron makes synaptic contact with only one climbing fiber. However, one climbing fiber makes contact with 1 to 10 Purkinje neurons. A few side branches leave each climbing fiber and synapse with the stellate cells and basket cells.

The **mossy fibers** are the terminal fibers of all other cerebellar afferent tracts. They have multiple branches and exert a much more diffuse excitatory effect. A single mossy fiber may stimulate **thousands** of Purkinje cells through the granule cells. What then is the function of the remaining cells of the cerebellar cortex, namely, the stellate, basket, and Golgi cells? Neurophysiologic research, using microelectrodes, would indicate that they serve as **inhibitory** interneurons. They not only limit the area of cortex excited but also probably influence the degree of Purkinje cell excitation produced by the climbing and mossy fiber input. By this means, fluctuating **inhibitory** impulses are transmitted by the Purkinje cells to the intracerebellar nuclei, which, in turn, modify muscular activity through the motor control areas of the brainstem and cerebral cortex. Thus, the Purkinje cells form the center of a **functional unit** of the cerebellar cortex.

Intracerebellar Nuclear Mechanisms

The deep cerebellar nuclei receive afferent nervous information from two sources: (1) the inhibitory axons from the Purkinje cells of the overlying cortex and (2) the excitatory axons that are branches of the afferent climbing and mossy fibers that are passing to the overlying cortex. In this manner, a given sensory input to the cerebellum sends excitatory information to the nuclei, which a short time later receive cortical processed inhibitory information from the Purkinje cells. Efferent information from the deep cerebellar nuclei leaves the cerebellum to be distributed to the remainder of the brain and spinal cord.

Cerebellar Cortical Neurotransmitters

Pharmacologic research has suggested that the excitatory climbing and mossy afferent fibers use **glutamate** (γ -aminobutyric acid [GABA]) as the excitatory transmitter on the dendrites of the Purkinje cells. Further research has indicated that other afferent fibers entering the cortex liberate **norepinephrine** and **serotonin** at their endings that possibly modify the action of the glutamate on the Purkinje cells.

Cerebellar Peduncles

The cerebellum is linked to other parts of the central nervous system (CNS) by numerous efferent and afferent fibers that are grouped together on each side into three large bundles, or peduncles (Fig. 6-9). The superior cerebellar peduncles connect the cerebellum to the midbrain, the middle cerebellar peduncles connect the cerebellum to the pons, and the inferior cerebellar peduncles connect the cerebellum to the medulla oblongata.

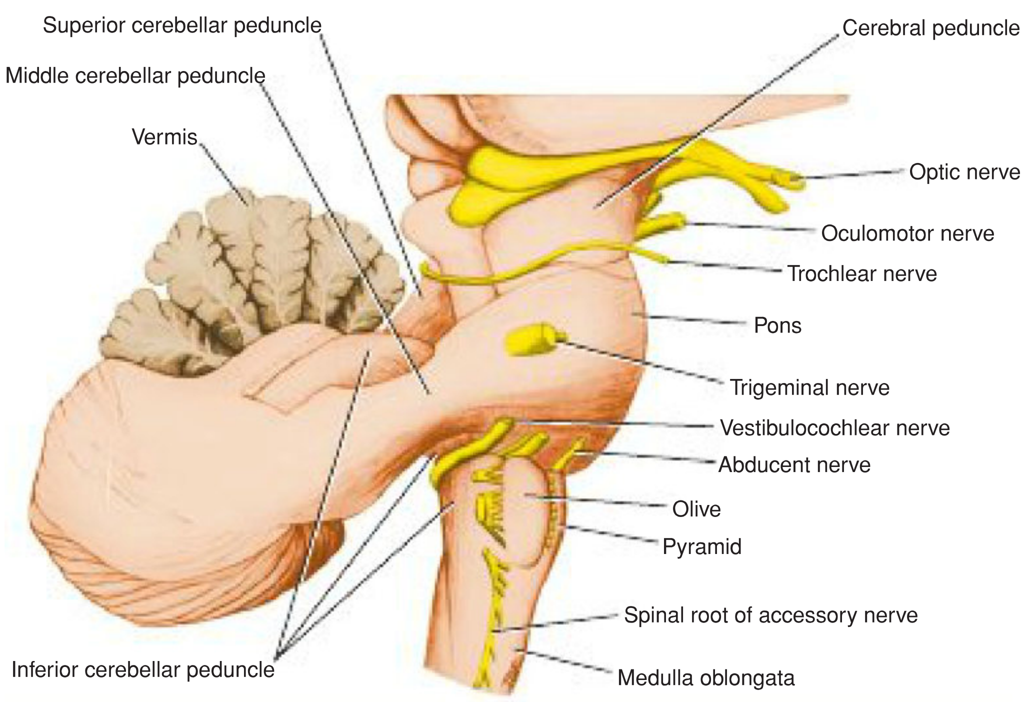

Figure 6-9 Three cerebellar peduncles connecting the cerebellum to the rest of the central nervous system.

CEREBELLAR AFFERENT FIBERS

The cerebellum receives major afferent tracts from the cerebral cortex, pons, medulla oblongata, and the spinal cord.

Cerebellar Afferent Fibers From the Cerebral Cortex

The cerebral cortex sends information to the cerebellum by three pathways: (1) the corticopontocerebellar pathway, (2) the cerebro-olivocerebellar pathway, and (3) the cerebroreticulocerebellar pathway.

Corticopontocerebellar Pathway

The corticopontine fibers arise from nerve cells in the frontal, parietal, temporal, and occipital lobes of the cerebral cortex and descend through the corona radiata and internal capsule and terminate on the pontine nuclei (Fig. 6-10). The pontine nuclei give rise to the **transverse fibers of the pons**, which cross the midline and enter the opposite cerebellar hemisphere as the middle cerebellar peduncle (see Figs. 5-18, 5-19).

Cerebro-Olivocerebellar Pathway

The cortico-olivary fibers arise from nerve cells in the frontal, parietal, temporal, and occipital lobes of the cerebral cortex and descend through the corona radiata and internal capsule to terminate bilaterally on the inferior olivary nuclei. The inferior olivary nuclei give rise to fibers that cross the midline and enter the opposite cerebellar hemisphere through the inferior cerebellar peduncle. These fibers terminate as the climbing fibers in the cerebellar cortex.

Cerebroreticulocerebellar Pathway

The corticoreticular fibers arise from nerve cells from many areas of the cerebral cortex, particularly the sensorimotor areas. They descend to terminate in the

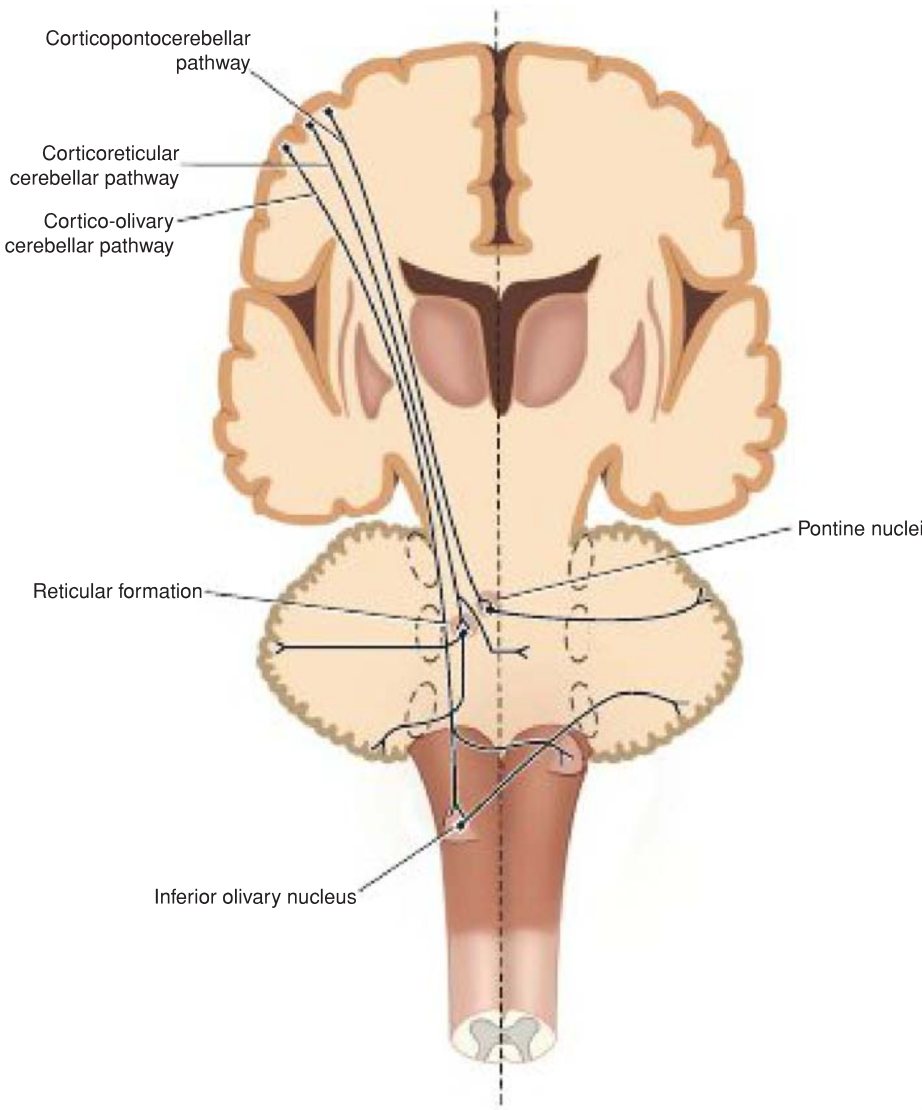

Figure 6-10 Cerebellar afferent fibers from the cerebral cortex. The cerebellar peduncles are shown as *ovoid dotted lines*.

reticular formation on the same side and on the opposite side in the pons and medulla. The cells in the reticular formation give rise to the reticulocerebellar fibers that enter the cerebellar hemisphere on the same side through the inferior and middle cerebellar peduncles.

This connection between the cerebrum and the cerebellum is important in the control of voluntary movement. Information regarding the initiation of movement in the cerebral cortex is probably transmitted to the cerebellum so that the movement can be monitored and appropriate adjustments in the muscle activity can be made.

Cerebellar Afferent Fibers From the Spinal Cord

The spinal cord sends information to the cerebellum from somatosensory receptors by three pathways: (1) the anterior spinocerebellar tract, (2) the posterior spinocerebellar tract, and (3) the cuneocerebellar tract.

Anterior Spinocerebellar Tract

The axons entering the spinal cord from the posterior root ganglion terminate by synapsing with the neurons in the **nucleus dorsalis** (Clarke column) at the base of the posterior gray column. Most of the axons of these neurons cross to the opposite side and ascend as the **anterior spinocerebellar tract** in the contralateral white column; some of the axons ascend as the anterior spinocerebellar tract in the lateral white column on the same side (Fig. 6-11). The fibers enter the cerebellum through the superior cerebellar peduncle and terminate as mossy fibers in the cerebellar cortex. Collateral

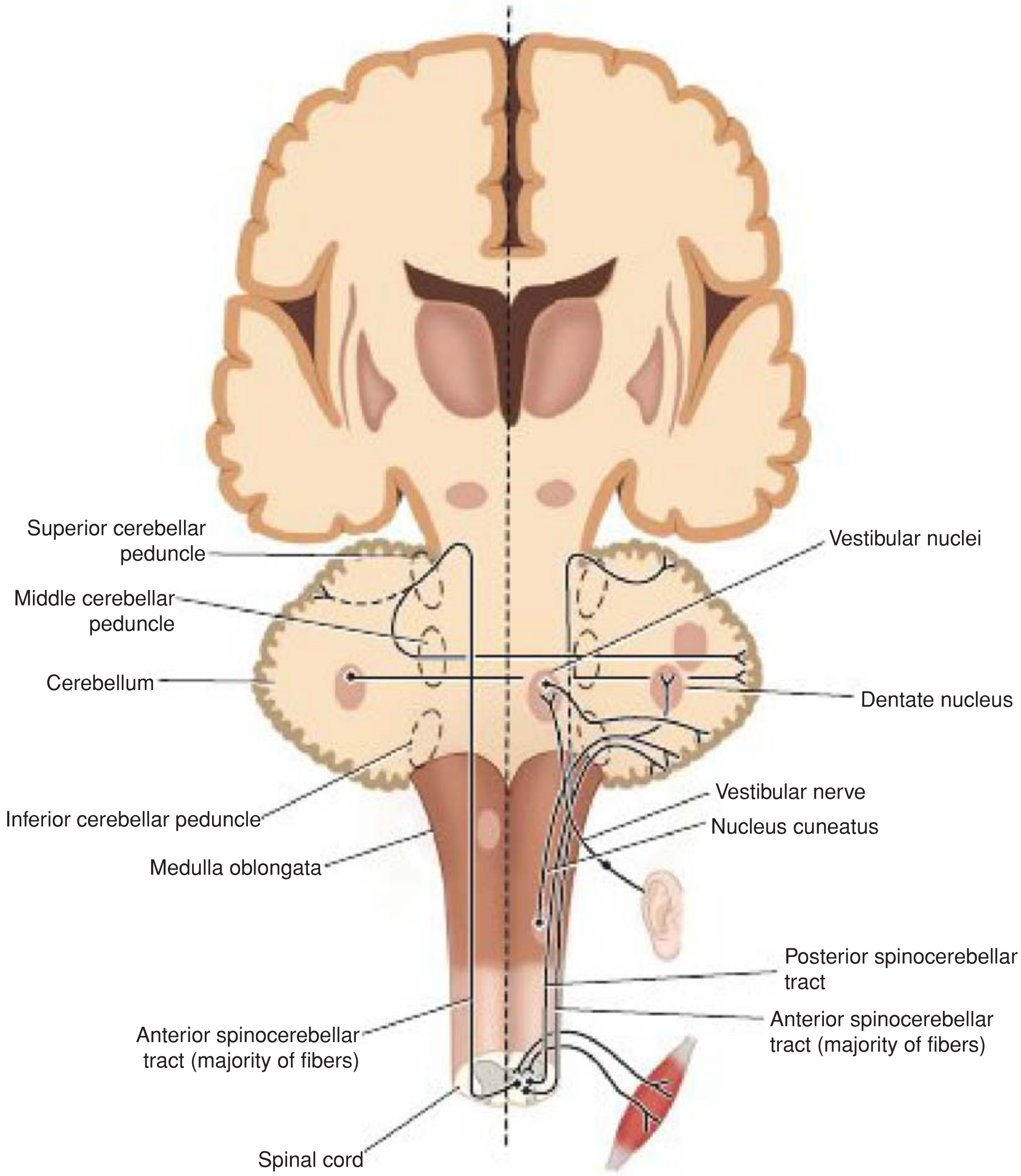

Figure 6-11 Cerebellar afferent fibers from the spinal cord and internal ear. The cerebellar peduncles are shown as *ovoid dotted lines.*

branches that end in the deep cerebellar nuclei are also given off. Those fibers that cross over to the opposite side in the spinal cord are thought to cross back within the cerebellum.

The anterior spinocerebellar tract is found at all segments of the spinal cord, and its fibers convey muscle joint information from the muscle spindles, tendon organs, and joint receptors of the upper and lower limbs. The cerebellum likely receives information from the skin and superficial fascia by this tract.

Posterior Spinocerebellar Tract

The axons entering the spinal cord from the posterior root ganglion enter the posterior gray column and terminate by synapsing on the neurons at the base of the posterior gray column. These neurons are known collectively as the nucleus dorsalis (Clarke column). The axons of these neurons enter the posterolateral part of the lateral white column on the same side and ascend as the **posterior spinocerebellar tract** to the medulla oblongata. Here, the tract enters the cerebellum through the inferior cerebellar peduncle and terminates as mossy fibers in the cerebellar cortex. Collateral branches that end in the deep cerebellar nuclei are also given off. The posterior spinocerebellar tract receives muscle joint information from the muscle spindles, tendon organs, and joint receptors of the trunk and lower limbs.

Cuneocerebellar Tract

These fibers originate in the nucleus cuneatus of the medulla oblongata and enter the cerebellar hemisphere on the same side through the inferior cerebellar peduncle (see Fig. 6-10). The fibers terminate as mossy fibers in the cerebellar cortex. Collateral branches that end in the deep cerebellar nuclei are also given off. The cuneocerebellar tract receives muscle joint information from the muscle spindles, tendon organs, and joint receptors of the upper limb and upper part of the thorax.

Cerebellar Afferent Fibers From the Vestibular Nerve

The vestibular nerve receives information from the inner ear concerning motion from the semicircular canals and position relative to gravity from the utricle and saccule. The vestibular nerve sends many afferent fibers directly to the cerebellum through the inferior cerebellar peduncle on the same side. Other vestibular afferent fibers pass first to the vestibular nuclei in the brainstem, where they synapse and are relayed to the cerebellum (see Fig. 6-11). They enter the cerebellum through the inferior cerebellar peduncle on the same side. All the afferent fibers from the inner ear terminate as mossy fibers in the flocculonodular lobe of the cerebellum.

Other Afferent Fibers

In addition, the cerebellum receives small bundles of afferent fibers from the red nucleus and the tectum.

The afferent cerebellar pathways are summarized in Table 6-1.

Table 6-1 Afferent Cerebellar Pathways

Pathway	Function	Origin	Destination
Corticopontocerebellar	Conveys control from cerebral cortex	Frontal, parietal, temporal, and occipital lobes	Via pontine nuclei and mossy fibers to cerebellar cortex
Cerebro-olivocerebellar	Conveys control from cerebral cortex	Frontal, parietal, temporal, and occipital lobes	Via inferior olivary nuclei and climbing fibers to cerebellar cortex
Cerebroreticulocerebellar	Conveys control from cerebral cortex	Sensorimotor areas	Via reticular formation
Anterior spinocerebellar	Conveys information from muscles and joints	Muscle spindles, tendon organs, and joint receptors	Via mossy fibers to cerebellar cortex
Posterior spinocerebellar	Conveys information from muscles and joints	Muscle spindles, tendon organs, and joint receptors	Via mossy fibers to cerebellar cortex
Cuneocerebellar	Conveys information from muscles and joints of upper limb	Muscle spindles, tendon organs, and joint receptors	Via mossy fibers to cerebellar cortex
Vestibular nerve	Conveys information of head position and movement	Utricle, saccule, and semicircular canals	Via mossy fibers to cortex of flocculonodular lobe
Other afferents	Conveys information from midbrain	Red nucleus, tectum	Cerebellar cortex

CEREBELLAR EFFERENT FIBERS

The entire output of the cerebellar cortex is through the axons of the Purkinje cells. Most of the axons of the Purkinje cells end by synapsing on the neurons of the deep cerebellar nuclei (see Fig. 6-4). The axons of the neurons that form the cerebellar nuclei constitute the efferent outflow from the cerebellum. A few Purkinje cell axons pass directly out of the cerebellum to the lateral vestibular nucleus. The efferent fibers from the cerebellum connect with the red nucleus, thalamus, vestibular complex, and reticular formation.

Globose-Emboliform-Rubral Pathway

Axons of neurons in the globose and emboliform nuclei travel through the superior cerebellar peduncle and cross the midline to the opposite side in the **decussation of the superior cerebellar peduncles** (Fig. 6-12). The fibers end by synapsing with cells of the contralateral red nucleus, which give rise to axons of the **rubrospinal tract**. Thus, this pathway crosses twice, once in the decussation of the superior cerebellar peduncle and again in the rubrospinal tract close to its origin. By this means, the globose and emboliform nuclei influence motor activity on the same side of the body.

Dentatothalamic Pathway

Axons of neurons in the dentate nucleus travel through the superior cerebellar peduncle and cross the midline to the opposite side in the **decussation of the superior cerebellar peduncle**. The fibers end by synapsing with cells in the contralateral **ventrolateral nucleus**

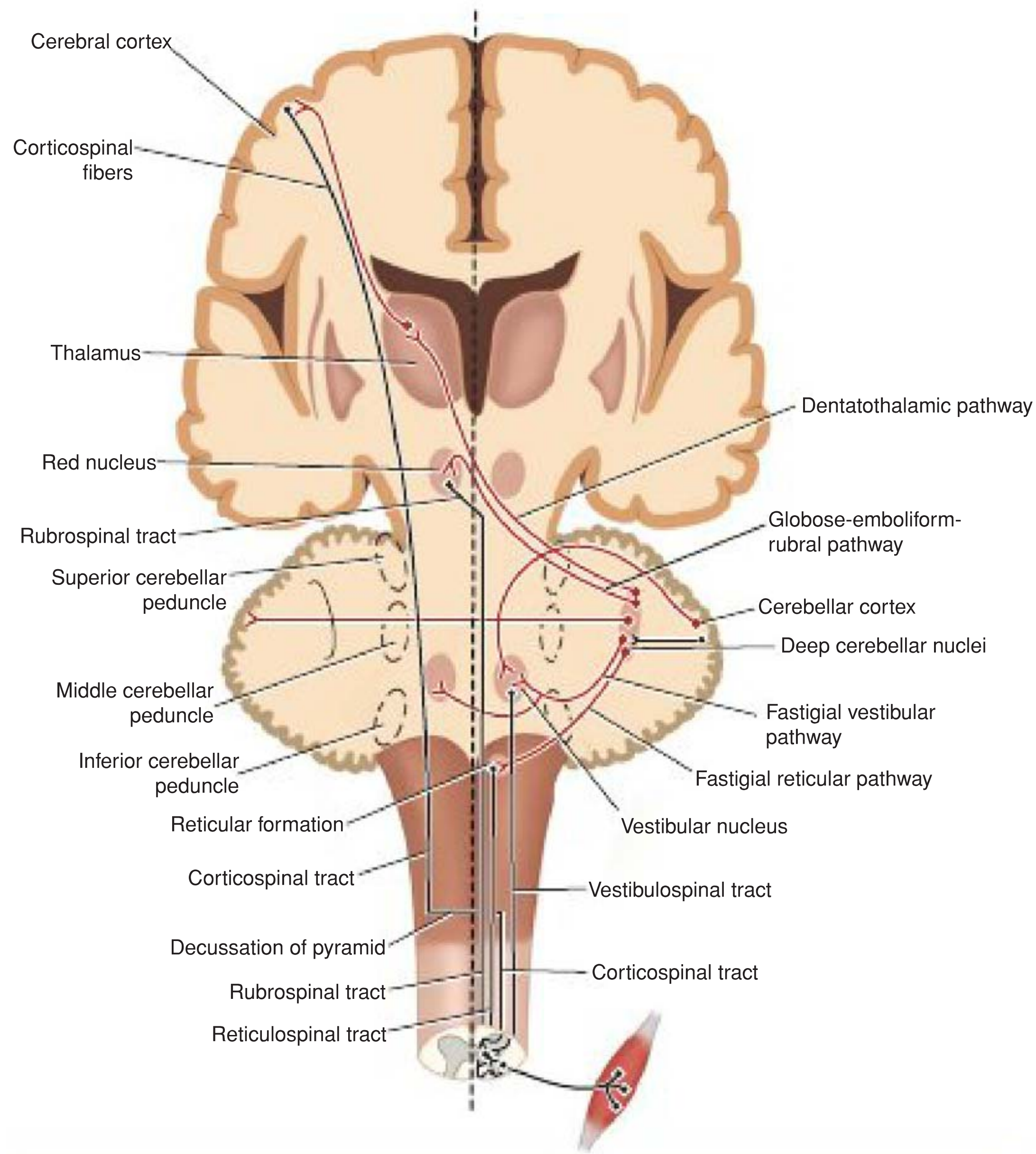

Figure 6-12 Cerebellar efferent fibers. The cerebellar peduncles are shown as *ovoid dotted lines*.

Table 6-2 Efferent Cerebellar Pathways[a]

Pathway	Function	Origin	Destination
Globose-emboliform-rubral	Influences ipsilateral motor activity	Globose and emboliform nuclei	To contralateral red nucleus, then via crossed rubrospinal tract to ipsilateral motor neurons in the spinal cord
Dentatothalamic	Influences ipsilateral motor activity	Dentate nucleus	To contralateral ventrolateral nucleus of the thalamus, then to contralateral motor cerebral cortex; corticospinal tract crosses midline and controls ipsilateral motor neurons in the spinal cord
Fastigial vestibular	Influences ipsilateral extensor muscle tone	Fastigial nucleus	Mainly to ipsilateral and to contralateral lateral vestibular nuclei; vestibulospinal tract to ipsilateral motor neurons in the spinal cord
Fastigial reticular	Influences ipsilateral muscle tone	Fastigial nucleus	To neurons of reticular formation; reticulospinal tract to ipsilateral motor neurons to the spinal cord

[a]Note that each cerebellar hemisphere influences the voluntary muscle tone on the same side of the body.

of the thalamus. The axons of the thalamic neurons ascend through the internal capsule and corona radiata and terminate in the primary motor area of the cerebral cortex. By this pathway, the dentate nucleus can influence motor activity by acting on the motor neurons of the opposite cerebral cortex; impulses from the motor cortex are transmitted to spinal segmental levels through the corticospinal tract. Remember that most of the fibers of the corticospinal tract cross to the opposite side in the decussation of the pyramids or later at the spinal segmental levels. Thus, the dentate nucleus is able to coordinate muscle activity on the same side of the body.

Fastigial Vestibular Pathway

The axons of neurons in the fastigial nucleus travel through the inferior cerebellar peduncle and end by projecting on the neurons of the **lateral vestibular nucleus** on both sides. Remember that some Purkinje cell axons project directly to the lateral vestibular nucleus. The neurons of the lateral vestibular nucleus form the **vestibulospinal tract**. The fastigial nucleus exerts a facilitatory influence mainly on the ipsilateral extensor muscle tone.

Fastigial Reticular Pathway

The axons of neurons in the fastigial nucleus travel through the inferior cerebellar peduncle and end by synapsing with neurons of the reticular formation. Axons of these neurons influence spinal segmental motor activity through the reticulospinal tract. The efferent cerebellar pathways are summarized in Table 6-2.

FUNCTIONS OF THE CEREBELLUM

The cerebellum receives afferent information concerning voluntary movement from the cerebral cortex and from the muscles, tendons, and joints. It also receives information concerning balance from the vestibular nerve and possibly concerning sight through the tectocerebellar tract. All this information is fed into the cerebellar cortical circuitry by the mossy fibers and the climbing fibers and converges on the Purkinje cells (see Fig. 6-8). The axons of the Purkinje cells project with few exceptions on the deep cerebellar nuclei. The output of the vermis projects to the fastigial nucleus, the intermediate regions of the cortex project to the globose and emboliform nuclei, and the output of the lateral part of the cerebellar hemisphere projects to the dentate nucleus. A few Purkinje cell axons pass directly out of the cerebellum and end on the lateral vestibular nucleus in the brainstem. Purkinje axons are generally believed to exert an inhibitory influence on the neurons of the cerebellar nuclei and the lateral vestibular nuclei.

The cerebellar output is conducted to the sites of origin of the descending pathways that influence motor activity at the segmental spinal level. In this respect, the cerebellum has no direct neuronal connections with the lower motor neurons but exerts its influence indirectly through the cerebral cortex and brainstem.

Physiologists have postulated that the cerebellum functions as a coordinator of precise movements by continually comparing the output of the motor area of the cerebral cortex with the proprioceptive information received from the site of muscle action; it is then able to bring about the necessary adjustments by influencing the activity of the lower motor neurons (Fig. 6-13). This is accomplished by controlling the timing and sequence of firing of the α and γ motor neurons. The cerebellum can possibly send back information to the motor cerebral cortex to inhibit the agonist muscles and stimulate the antagonist muscles, thus limiting the extent of voluntary movement.

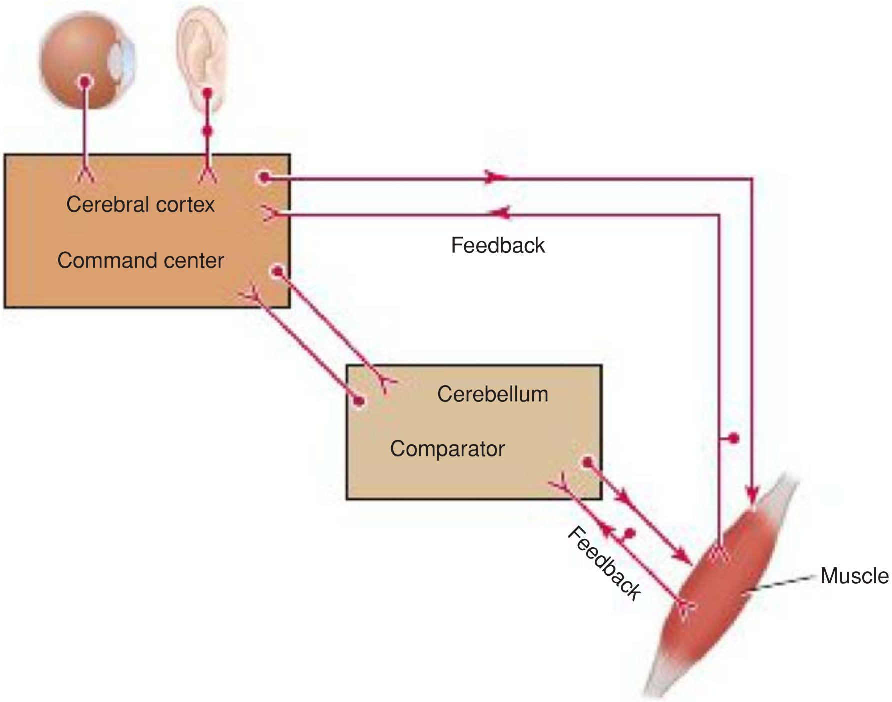

Figure 6-13 Cerebellum serving as a comparator.

Clinical Notes

General Considerations

Each cerebellar hemisphere is connected by nervous pathways principally with the same side of the body; thus, a **lesion in one cerebellar hemisphere gives rise to signs and symptoms that are limited to the same side of the body**. The main connections of the cerebellum are summarized in Figure 6-14.

The essential function of the cerebellum is to coordinate, by synergistic action, all reflex and voluntary muscular activity. Thus, it graduates and harmonizes muscle tone and maintains normal body posture. It permits voluntary movements, such as walking, to take place smoothly with precision and economy of effort. It must be understood that although the cerebellum plays an important role in skeletal muscle activity, it is not able to initiate muscle movement.

Signs and Symptoms of Cerebellar Disease

While the importance of the cerebellum in the maintenance of muscle tone and the coordination of muscle movement has been emphasized, it should be remembered that the symptoms and signs of acute lesions differ from those produced by chronic lesions. Acute lesions produce sudden, severe symptoms and signs, but there is considerable clinical evidence to show that patients can recover completely from large cerebellar injuries. This suggests that other CNS areas can compensate for loss of cerebellar function. Chronic lesions, such as slowly enlarging tumors, produce symptoms and signs that are much less severe than those of acute lesions. The reason for this may be that other CNS areas have time to compensate for loss of cerebellar function. The following symptoms and signs are characteristic of cerebellar dysfunction.

Hypotonia

The muscles lose resilience to palpation. There is diminished resistance to passive movements of joints. Shaking the limb produces excessive movements at the terminal joints. The condition is attributable to loss of cerebellar influence on the simple stretch reflex.

Postural Changes and Alteration of Gait

The head is often rotated and flexed, and the shoulder on the side of the lesion is lower than on the normal side. The patient assumes a wide base when he or she stands and is often stiff legged to compensate for loss of muscle tone. When the individual walks, he or she lurches and staggers toward the affected side.

Disturbances of Voluntary Movement (Ataxia)

The muscles contract irregularly and weakly. **Tremor** occurs when fine movements, such as buttoning clothes, writing, and shaving, are attempted. Muscle groups fail to work harmoniously, and there is **decomposition of movement**. When the patient is asked to touch the tip of the nose with the index finger, the movements are not properly coordinated, and the finger either passes the nose (past-pointing) or hits the nose. A similar test can be performed on the lower limbs by asking the patient to place the heel of one foot on the shin of the opposite leg.

Dysdiadochokinesia

Dysdiadochokinesia is the inability to perform alternating movements regularly and rapidly. Ask the patient to pronate and supinate the forearms rapidly. On the side of

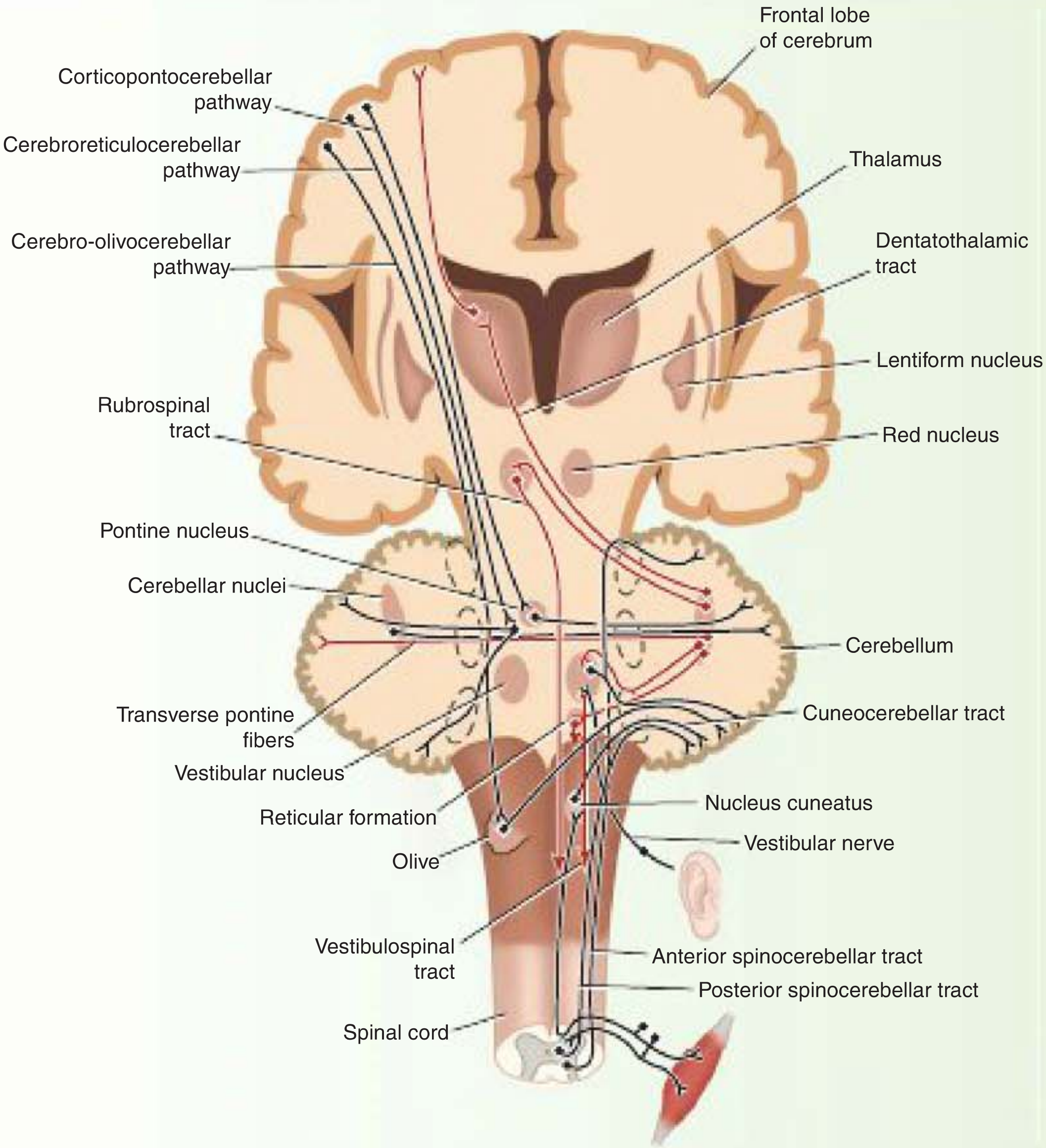

Figure 6-14 Some of the main connections of the cerebellum. The cerebellar peduncles are shown as *ovoid dashed lines*.

the cerebellar lesion, the movements are slow, jerky, and incomplete.

Disturbances of Reflexes

Movement produced by tendon reflexes tends to continue for a longer period of time than normal. The **pendular knee jerk**, for example, occurs following tapping of the patellar tendon. Normally, the movement occurs and is self-limited by the stretch reflexes of the agonists and antagonists. In cerebellar disease, because of loss of influence on the stretch reflexes, the movement continues as a series of flexion and extension movements at the knee joint; that is, the leg moves like a pendulum.

Disturbances of Ocular Movement

Nystagmus, which is essentially an ataxia of the ocular muscles, is a rhythmical oscillation of the eyes. It is more easily demonstrated when the eyes are deviated in a horizontal direction. This rhythmic oscillation of the eyes may be of the same rate in both directions **(pendular nystagmus)** or quicker in one direction than in the other **(jerk nystagmus)**. In the latter situation, the movements are referred to as the slow phase away from the visual object, followed by a quick phase back toward the target. The quick phase is used to describe the form of nystagmus. For example, a patient is said to have a nystagmus to the left if the quick phase is to the left and the slow phase is to the right. The movement of nystagmus may be confined to one plane and may be horizontal or vertical, or it may be in many planes when it is referred to as rotatory nystagmus.

The posture of the eye muscles depends mainly on the normal functioning of two sets of afferent pathways. The first is the visual pathway whereby the eye views the object of interest, and the second pathway is much more complicated and involves the labyrinths, the vestibular nuclei, and the cerebellum.

Disorders of Speech

Dysarthria occurs in cerebellar disease because of ataxia of the muscles of the larynx. Articulation is jerky, and the syllables often are separated from one another. Speech tends to be explosive, and the syllables often are slurred.

In cerebellar lesions, paralysis and sensory changes are not present. Although muscle hypotonia and incoordination may be present, the disorder is not limited to specific muscles or muscle groups; rather, an entire extremity or the entire half of the body is involved. If both cerebellar hemispheres are involved, then the entire body may show disturbances of muscle action. Even though the muscular contractions may be weak and the patient may be easily fatigued, there is no atrophy.

Cerebellar Syndromes

Vermis Syndrome

The most common cause of vermis syndrome is a **medulloblastoma** of the vermis in children. Involvement of the flocculonodular lobe results in signs and symptoms related to the vestibular system. Since the vermis is unpaired and influences midline structures, muscle incoordination involves the head and trunk and not the limbs. There is a tendency to fall forward or backward. There is difficulty in holding the head steady and in an upright position. There also may be difficulty in holding the trunk erect.

Cerebellar Hemisphere Syndrome

Tumors of one cerebellar hemisphere may be the cause of cerebellar hemisphere syndrome. The symptoms and signs are usually unilateral and involve muscles on the side of the diseased cerebellar hemisphere. Movements of the limbs, especially the arms, are disturbed. Swaying and falling to the side of the lesion often occur. Dysarthria and nystagmus are also common findings. Disorders of the lateral part of the cerebellar hemispheres produce delays in initiating movements and inability to move all limb segments together in a coordinated manner but show a tendency to move one joint at a time.

Common Diseases Involving the Cerebellum

One of the most common diseases affecting cerebellar function is acute alcohol poisoning. This occurs as the result of alcohol acting on GABA receptors on the cerebellar neurons.

The following frequently involve the cerebellum: congenital agenesis or hypoplasia, trauma, infections, tumors, multiple sclerosis, vascular disorders such as thrombosis of the cerebellar arteries, and poisoning with heavy metals.

The many manifestations of cerebellar disease can be reduced to two basic defects: hypotonia and loss of influence of the cerebellum on the activities of the cerebral cortex.

Key Concepts

Cerebellum

- The cerebellum is composed of an outer covering of gray matter called the cortex and inner white matter. Embedded in the white matter of each hemisphere are three masses of gray matter forming the four intracerebellar nuclei.
- The gray matter of the cortex is divided into three layers: the external, molecular layer; the middle, Purkinje layer; and the inner, granular layer.
- Basket and stellate cells are found in the molecular layer and are scattered throughout the dendritic arborizations of the Purkinje cells, whose cell bodies are found within the Purkinje layer.
- Granule cells (and Golgi cells) are found throughout the granular layer and have synaptic contact with mossy fiber input (cerebellar afferent tracts). The axon of each granule cell branches and runs parallel to the long axis of the cerebellar folium.
- Climbing fibers are terminal fibers of the olivocerebellar tracts. A single Purkinje neuron makes synaptic contact with only one climbing fiber.
- Mossy fibers are the terminal fibers of all other cerebellar afferent tracts. Each mossy fiber communicates with thousands of Purkinje cells through the granule cells.

Cerebellar Afferent Fibers

- The cerebellum receives three afferent pathways from the cerebrum and is important for monitoring and control of voluntary movements.
- The cerebellum also receives three afferent pathways from the spinal cord, all of which supply the cerebellum with muscle and joint information of the limb and trunk.

Cerebellar Efferent Fibers

- The output of the cerebellum is through Purkinje cell axons, most of which synapse on the neurons of the deep cerebellar nuclei.
- The efferent fibers from the deep nuclei connect with the red nucleus (globose-emboliform-rubral), thalamus (dentatothalamic), vestibular complex (fastigial vestibular), and reticular formation (fastigial reticular).

Cerebellar Functions

- The cerebellum functions as a coordinator of precise movements by continually comparing the output of the motor area of cerebral cortex with the proprioceptive information received from the site of muscle action, and makes necessary adjustments.