Chapter

# Anatomy of Cerebellum

*Rajasekhar Sajja Srinivasa Siva Naga*

## Abstract

The cerebellum receives inputs from spinal cord, cerebrum, brainstem, and sensory systems of the body and controls the motor system of the body. The Cerebellum harmonizes the voluntary motor activities such as maintenance of posture and equilibrium, and coordination of voluntary muscular activity including learning of the motor behaviours. Cerebellum occupies posterior cranial fossa, and it is relatively a small part of the brain. It weighs about one tenth of the total brain. Cerebellar lesions do not cause motor or cognitive impairment. However, they cause slowing of movements, tremors, lack of equilibrium/balance. Complex motor action becomes shaky and faltering.

**Keywords:** Cerebellum, Spinocerebellar ataxia, Cortex, Medulla, Peduncles, Nuclei

## 1. Introduction

The Cerebellum is the largest part of the hindbrain and develops from the alar plates (rhombic lips) of the metencephalon.

It lies between the temporal and occipital lobes of cerebrum and the brainstem in the posterior cranial fossa. It is attached to the posterior surface of the brainstem by three large white fibre bundles. It is attached to the midbrain by superior cerebellar peduncle, pons by middle cerebellar peduncle, and medulla by inferior cerebellar peduncle.

Cerebellum is concerned with three primary functions: a) coordination of voluntary motor functions of the body initiated by the cerebral cortex at an unconscious level, b) maintenance of balance, and posture, c) Maintenance of muscle tone. It receives and integrates the sensory inputs from the cerebrum and the spinal cord necessary for a planning and smooth coordination of the movements [1].

Cerebellar lesions result in irregular and uncoordinated, awkward intentional muscle movements. Cerebellar lesions often present as occipital headache that worsen at night, nausea, vomiting and unsteadiness. On examination the patients often have bilateral papilledema, nystagmus, slight slurred speech, irregular and ataxic movements [2].

## 2. External features of cerebellum

Cerebellum consists three parts; two laterally located **hemispheres** joined in the midline by the **vermis** (*worm*). Somatotopy: Vermis controls the central parts of the body (trunk) and its lesions produce truncal ataxia. And each hemisphere control ipsilateral limb, and their lesion causes ataxia of ipsilateral limbs. Superior surface of the cerebellum is separated from the occipital lobe cerebrum

by tentorium cerebelli of dura mater. Superior vermis protrudes above the cerebellar hemispheres whereas the inferior vermis is buried in a deep groove present between the two bulging lateral lobes. The surface of the cerebellum features highly convoluted folds(folia) that are oriented transversely. These folds are separated by fissures of variable depths. Some of the deep fissures can be used as landmarks to anatomically divide the Cerebellum into three lobes: **anterior, posterior** and **flocculonodular lobes**. On the superior surface, a deep **primary fissure** separates the small anterior lobe from the large posterior lobe. On the inferior surface, a prominent **posterolateral fissure** isolates the flocculus of cerebellar hemisphere together with the nodule of the vermis from the rest of the cerebellum as flocculonodular lobe [2].

### 2.1 Cerebellar lobes (Phylogenetic/Evolutionary and Functional divisions)

a. Antezrior Lobe (Spinocerebellum-Spinocerebellar tract)

- It lies anterior to the primary fissure. It regulates the muscle tone. It receives input from muscle spindles (stretch receptor) and Golgi tendon organs (GTOs) through spinocerebellar tract.

b. Posterior lobe (Neocerebellum-Corticopontocerebellar tract)

- It lies between the primary fissure and posterolateral fissure. It regulates the voluntary motor activity. It receives enormous inputs from neocortex through cortico-pontocerebellar tract.

c. Flocculonodular lobe (Vestibulocerebellum- Vestibulocerebellar tract)

- It consists of flocculus and the nodule (vermis). It regulates the maintenance of balance and posture.

### 2.2 Longitudinal organisation of Cerebellum

Cerebellum consists of three functional zones that are longitudinally oriented, and these zones are connected to specific cerebellar nuclei.

a. **Median (Vermal) zone** of hemisphere consists of the cortex of the vermis and it is connected to fastigial nucleus.

b. **Paramedian (Paravermal) zone** consists of the cortex of the hemisphere that is immediately adjacent to the vermis and it is connected to nucleus interpositus (Globose and Emboliform nuclei)

c. **Lateral zone** consists of cortex of the hemisphere that is exclusive of vermal and paravermal regions [3].

## 3. Internal structure of the cerebellum

Like the cerebral cortex, the **Cerebellum** also consists of outer shell of **grey matter** (cerebellar cortex) and the inner core **white matter**. The white matter consists of afferents and efferent fibres that go to and from the cortex. The white

mater present underneath the grey mater resembles branches of a tree, hence named *arbor vitae cerebelli* (tree of life). The fibres reach the cortex in a characteristic branch like projections.

The four cerebellar nuclei are distributed deeply within the white mater in each cerebellar hemisphere. The cerebellar nuclei, while connected to the cerebellar cortex, give off the outflow form the cerebellum to the other parts of the brain. The connections are primarily to brainstem nuclei and the thalamus.

### 3.1 Cerebellar cortex

On the surface of the cerebellum, a highly convoluted cortex forms numerous transversely oriented folium. The cerebellar cortex is filled with cerebellar neuronal cell bodies, dendrites, and various synapses. The cortex is histologically divided into three layers:

a. Outer, **Molecular layer** (Fibre rich)

b. Middle, **Purkinje cell layer**

c. Inner, **Granule cell layer** (Granule cells)

a. **Molecular layer:** It is the outer most layer, present adjacent to the pia mater. *White fibres*: It contains dendritic arborisation of Purkinje cells and parallel fibres of Granule cells. *Cell bodies*: It contains **stellate** (outer) **cells** and **basket** (inner stellate) **cells**.

b. **Purkinjee cell layer:** It is present between the molecular and the granule cell layer. It consists of single row of cell bodies of **Purkinje cells**. The dendrites branch extensively and extend into the outer molecular layer. The dendritic branches are flattened in a single axis and are oriented at right angles to the long axis of the folium and the parallel fibres. Because of this arrangement, the branches of Purkinje fibres are perpendicularly traversed by the parallel fibres of molecular layer. The axons of Purkinje cells *form the only output* from the cerebellar cortex. Axons of the Purkinje cells end in cerebellar nuclei (dentate, emboliform, globose, fastigial) and vestibular nuclei and has an inhibitory effect (gama-aminobutyric acid, GABA) on them. Therefore, entire cerebellar output is facilitated through the inhibition of the cells of deep cerebellar nuclei.

**Excitatory input:** Parallel fibres of granule cells (Glutamate) and climbing fibres (Aspartate) excite the Purkinje cells.
**Inhibitory inputs:** Golgi cells, basket cells and stellate cells inhibit (GABA) the Purkinje cells.

c. **Granule cell layer:** It is present between Purkinje cell layer and the white mater of cerebellum and contains granule cells**.** It contains granule cells, Golgi cells, and cerebellar glomeruli. Cerebellar glomeruli are made up of granule cell dendrite, Golgi tenson axon and mossy fibre rosette. The parallel fibres of **granule cells** excite Purkinje cells, basket cells, stellate cells, Golgi cells.

**Excitatory input:** Mossy fibres excite the granule cells.
**Inhibitory inputs:** Golgi cells inhibit the granule cells

## 4. White Fibres of cerebellum

Afferents travel through cerebellar peduncles and reach the cerebellar cortical neurons to stimulate them. Based on the origin, the afferents reaching cerebellar cortex are classified as: 1) Climbing fibres, 2) Mossy fibres.

### 4.1 Mossy fibres

The afferent fibres (excitatory) of **spinocerebellar tract, pontocerebellar tract, and vestibulocerebellar tract** are called as mossy fibres. Mossy fibres branch and terminate in an excitatory synapse with the granule cells as mossy fibre rosette, of several folia. The axons of granule cells enter the molecular layer, through Purkinje layer and split to form two **parallel fibres** which run along the long axis of the folium. Mossy fibres excite granule cells which discharge via their parallel fibres.

Spinocerebellar tract + Olivocerebellar tract → Mossy fibres → +Granule cells → Parallel fibres

### 4.2 Climbing fibres

The afferent fibres (excitatory, aspartate) of **olivocerebellar tract** from contralateral inferior olivary nucleus of medulla are called as climbing fibres. They terminate on the dendrites of Purkinje cells and the deep cerebellar nuclei [4].

## 5. Cerebellar nuclei

**Four** cerebellar nuclei lie deep within the cerebellar white matter of each hemisphere. They are arranged from lateral to medial as follows:

- Dentate Nucleus (Tooth like serrated edge)
- Emboliform nucleus (Plug or Wedge-shaped)
- Globose nucleus (Spherical shaped)
- Fastigial nucleus (Peak of the Fourth ventricle: Fastigium)

### 5.1 Extracerebellar afferents of cerebellar nuclei

The collateral branches of Mossy fibers coming from: a) vestibular nuclei, b) reticular nuclei, c) pontine nuclei, d) spinocerebellar tract.

Among the deep cerebellar nuclei, the dentate nucleus with its crinkled bag-like appearance is the largest and the only nucleus visible to the naked eye. The dentate nucleus receives afferent fibers from the inferior olivary nucleus of the medulla, which also looks like a crinkled bag.

### 5.2 Intracerebellar afferents of cerebellar nuclei

Purkinje cells of the cerebellar cortex.

### 5.3 Efferent from Cerebellum

The majority of the efferent fibers leaving the cerebellum originate from the deep cerebellar nuclei. The efferent fibers reach: a) reticular nuclei, b) vestibular nuclei, c) red nucleus, ventral lateral nucleus of the thalamus.

## 6. Functional anatomy of cerebellum

Functionally, anatomically, and phylogenetically/ evolutionarily cerebellum can be divided into Archicerebellum, Paleocerebellum, Neocerebellum.

a. **Archicerebellum** consists of the flocculonodular lobe and nucleus fastigius. It is evolutionarily the first one to develop. **Connections:** Vestibulocerebellar: vestibular receptors of labyrinths, vestibular, and reticular nuclei through inferior cerebellar peduncle, spinal cord. **Function:** Maintenance of balance (equilibrium), posture, and coordination of eye movements.

**Bilateral balance control by Archicerebellum**

Superior colliculus + Striate cortex ➔Inferior cerebellar peduncle➔ Flocculonodular lobe➔Purkinje fibres (cerebellar cortex)➔Fastigeal Nucleus➔ Inferior cerebellar peduncle➔ IPSILATERAL & CONTRALATERAL vestibular nuclei + Reticular formation ➔ Vestibulospinal tract, Reticulospinal tracts➔ Spinal cord.

b. **Paleocerebellum** consists of the vermis, paravermis, fastigial nucleus, emboliform nucleus. **Function:** Controls the tone and posture of the trunk and proximal limb muscles through the vermal-cerebellar pathway. **Connections: Spinocerebellar:** Spinal cord and red nucleus through inferior and superior cerebellar peduncle.

**Contralateral muscle tone and posture control by Paleocerebellum**

Receptors of Muscle, Joint, Skin➔ Dorsal Spinocerebellar tract ➔ Inferior cerebellar peduncle➔IPSILATERAL vermis +paravermis➔ Globose nucleus + emboliform Nucleus+ Fastigial nucleus➔ Superior cerebellar peduncle➔ CONTRALATERAL red Nucleus➔ Rubrospinal tract.

Receptors of Muscle, Joint, Skin ➔ Ventral spinocerebellar tract➔ Superior cerebellar peduncle➔ IPSILATERL vermis+ paravermis➔ Globose nucleus+ Emboliform nucleus➔ Superior cerebellar peduncle➔ CONTRALATERAL Red nucleus➔ Rubrospinal tract.

c. **Neocerebellum** consists of the remaining cerebellar hemisphere (except pyramid and uvula) and dentate nucleus. **Function:** Controls the highly skilled muscle coordination and trajectory, speed, and force of movements. **Connections: Cortico-pontocerebellar:** Pontine nuclei, cerebral cortex.

**Coordination of movement by Neocortex**

Planning+ execution of movement➔Cerebral cortex➔ corticopontine fibres➔ Pontine nuclei➔ Pontocerebellar fibres➔ CONTRALATERAL middle cerebellar peduncle➔ Lateral parts of cerebellar hemispheres ➔ Dentate nucleus➔ Superior cerebellar peduncle➔ Contralateral Red nucleus (rubrothalamic cells) + Ventral lateral nucleus of Thalamus➔ motor cortex of frontal lobe of cerebrum➔ Corticospinal tract+ Corticobulbar tract

## 7. Cerebellar Peduncles

These are the white fibre bundles that join the different parts of the brain stem with the cerebellum.

### 7.1 Superior cerebellar peduncle (Midbrain➔ Cerebellum)

**Afferent fibers from**:

- *Spinal cord* (**Ventral spinocerebellar tract**, **Major input**)
- *Tectum of the midbrain* (Tectocerebellar fibers)
- *Hypothalamus* (Hypothalamocerebellar fibers)
- *Locus ceruleus* (Ceruleocerebellar fibers)

**Efferent fibers to**:

- Globose and emboliform nuclei➔ contralateral *red nucleus* (Cerebellorubral fibers)
- Dentate nucleus➔ contralateral *red nucleus* (Dentatorubral fibers)
- Dentate nucleus ➔ contralateral *Thalamus*: Ventral lateral nucleus (**Dentatothalamic fibers, Major output)**
- Dentate nucleus➔ contralateral *inferior olivary nucleus* (Cerebello-olivary fibres)
- Nucleus fastigius ➔ *Reticular nuclei* (Cerebelloreticular fibers)

### 7.2 Middle cerebellar peduncle (Pons ➔ Cerebellum)

**Afferent fibers from**:

- Contralateral *pontine nuclei* (**Cortico-ponto-cerebellar fibers, Major input**)
- *Ipsilateral Reticular formation*➔ vermis (Reticulocerebellar fibers)
- *Raphe nuclei of pons* (Seratogenic fibers)

**Efferent fibers to: No efferents.**

### 7.3 Inferior cerebellar peduncle

**Afferent fibers from:**

- Ipsilateral *thoracic nucleus of Spinal cord*, Clarke's column (**Dorsal spinocerebellar tract, Major input**).
- Ipsilateral *accessory cuneate nucleus* (**Cuneocerebellar tract, Major input**),
- *Inferior olivary nucleus* (**Olivocerebellar tract➔** climbing fibers, **Major input**)
- Contralateral *medial and dorsal accessory olivary nucleus* (Parolivocerebellar tract),

- *Vestibular nuclei* (Vestibulocerebellar tract)
- *Lateral and paramedian reticular nuclei* (Reticulocerebellar tract)

**Efferent fibers to**:

- Ipsilateral flocculonodular lobe ➔ bilateral *Vestibular nuclei* (Cerebellovestibular fibers)
- Bilateral Fastigial nuclei➔ *reticular formation* of pons and medulla (Cerebelloreticluar fibers)
- *Inferior olivary nucleus* (Cerebello-olivary fibers)

### 7.4 Major pathways

Cerebellum-Cerebrum-Cerebellum circuit
Purkinje cells ➔ Dentate nucleus ➔ superior cerebellar peduncle➔ dentatothalamic tract➔ Contralateral ventral lateral nucleus of Thalamus ➔ primary motor cortex of precentral gyrus (Brodmann's area 4, motor strip)➔ corticopontine tract➔ pontine nuclei➔ pontocerebellar tract➔ contralateral cerebellar cortex➔ mossy fibers.

## 8. Blood supply of Cerebellum

The cerebellum is supplied by posterior circulation originated from vertebral arteries. The vertebral artery gives rise to the posterior inferior cerebellar artery (PICA), which supplies the posterior part of the inferior surface of the cerebellum. The basilar artery gives rise to the anterior inferior cerebellar artery (AICA), which supplies the anterior part of the inferior surface. The superior cerebellar artery (SCA) supplies the superior surface of the cerebellum [1].

## 9. In the clinic

### 9.1 Cerebellar disorders

a. Hypotonia (reduced muscle tone) and ataxia (loss of coordinated muscular movements) (Most characteristic signs)

b. Dysequilibrium: loss of balance, gait, and trunk ataxia

c. Dyssynergia (loss of coordinated muscle activity): a) Dysmetria (inability to do the finger-nose test), b) Intentional tremor on voluntary movements, c) Dysdiadochokinesia (inability to do rapid alternating repetitive movements).

d. Ipsilateral reduced tendon reflexes

e. Asthenia

f. Cerebellar Nystagmus (coarse)

### 9.2 Midline lesions

The midline lesions of the cerebellum (vermis) cause loss of control of trunk posture resulting in truncal ataxia. Patients present with the inability to sit or stand, as there would be involuntary swinging of the body back and forth to stabilize around the center of gravity.

### 9.3 Unilateral cerebellar lesions

Cerebellar tracts **do not decussate** like the cerebrum. The symptoms (limb ataxia) produced by the lesions of cerebellar hemispheres are ipsilateral. Unilateral lesions of cerebellar hemispheres cause ipsilateral loss of arm or leg coordination resulting in an unsteady gait (No motor or sensory loss). Limb ataxia can be tested by asking the patient to do a "**heel to shin**" test. When patients with limb ataxia try to walk, the body has difficulty coordinating muscle movements, leading to shifting **the center of gravity**. When there is a fall due to a significant shift in the center of gravity, the fall is usually towards the same **side of the lesion**. The patient often compensates for this by lowering their center of gravity by **wide stepped gait** [5]**.**

### 9.4 Bilateral cerebellar dysfunction

Bilateral cerebellar dysfunction causes the following symptoms:

a. **Dysarthria**: slurring of speech

b. **Cerebellar ataxia**: unsteady, wide-based, staggering gait and incoordination of both arms

c. **Nystagmus**: involuntary rhythmic to-and-fro movements of the eyeball. Symptoms increase when the gaze is pointed to the side of the lesion.

Diseases in which cerebellum is affected bilaterally: a) hypothyroidism, b) alcoholic intoxication, c) multiple sclerosis, d) degenerative diseases, e) metabolic disorders).

**Charcot's triad:** A characteristic combination of nystagmus, dysarthria, and intentional tremor are observed in multiple sclerosis.

### 9.5 Other causes of cerebellar dysfunction

Tumours (Astrocytoma, Medulloblastoma, Ependymomas), Hypertensive hemorrhage, cerebellar infarctions.

### 9.6 Cerebellar dysfunction + Hydrocephalus

Cerebellar infarctions (edema), cerebellar tumors compressing IV$^{th}$ ventricle.

### 9.7 Points to ponder

Anterior vermis syndrome, Posterior vermis syndrome, Hemispheric syndrome [5].

## 10. Conclusion

Cerebellum consists of median vermis and prominent lateral hemispheres. It forms the roof of the fourth ventricle behind the brain stem. It is attached to the parts of brainstem by cerebellar peduncles which are large white fibre bundles carrying afferent and efferent fibres of cerebellum. Afferent systems of cerebellum include climbing fibres and mossy fibres. It also receives fibres from brainstem reticular formation. Climbing fibres are connected to the contralateral inferior olivary nucleus of medulla oblongata, at one end, and the proximal dendrites of a single Purkinjee cell in the cerebellar cortex, at the other end. Mossy fibres are connected to spinal cord, brain stem, at one end and multiple Purkinjee cells of cerebellar cortex at another end.

## 11. Cerebellum and Spinocerebellar ataxia

**Case study:** 55 old male presents with a history of poor hand coordination, slurred speech, rapid eye movements, reduced intellectual function. Physical examination reveals cerebellar ataxia, spasticity, negative Babinski sign. Brain CT scan showed mild cerebral and marked cerebellar atrophy.

**Diagnosis:** Spinocerebellar ataxia.

## 12. Spinocerebellar ataxia

**Introduction:** Spinocerebellar ataxias (SCA), are a group of hereditary ataxias transmitted by autosomal dominant inheritance, in which there is a progressive and slow degeneration of cerebellum and certain parts of spinal cord. Among the many types of SCAs, they are classified based on the gene mutation responsible for a specific type of SCA. The types are described as SCA1 through SCA40.

**Symptoms:** The signs and symptoms across the different types generally include abnormal speech (dysarthria), uncoordinated walk (gait), poor hand-eye coordination, vision problems and difficulty in processing, learning and remembering information. The main symptom include ataxia, where smooth coordination of voluntary motor functions is lost, and there is also nystagmus where the vestibulo-cerebellar fibres and vestibulo-cerebellum are involved. Owing to the degenerative nature of the disease, not only dorsal and ventral spinocerebellar fibres carrying proprioceptive fibres from skeletal muscles and joints, almost all the functions of the cerebellum are affected in Spinocerebellar ataxias.

**Etiology:** Certain types of SCA are caused due to mutation called trinucleotide repeat expansion, where a particular segment of DNA is repeated number of times beyond the tolerable limit. Such nucleotide repeats are unstable and alter their length while passing through generations and often lead to early age onset of the disease. The risk of transmission of the disease from the affected generation to the next is 50%.

**Diagnosis:** If the disease-causing mutation is known then the carrier testing for at-risk relatives and prenatal testing can be done to diagnose the disease.

**Treatment:** There is no specific treatment for SCA. For ataxia, physiotherapy to strengthen the muscles can be done. Physical aids such as crutches and walkers can be used to assist daily activity of the patient [2].

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## Author details

Rajasekhar Sajja Srinivasa Siva Naga
Department of Anatomy, Jawaharlal Institute of Postgraduate Medical Education and Research, Puducherry, India

*Address all correspondence to: drsrinivas83@gmail.com

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