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# Cerebellum: Its Anatomy, Functions and Diseases

Rajani Singh

Abstract

Cerebellum is the largest part of the hindbrain and weighs about 150 g. It is enshrined in posterior cranial fossa behind the pons and medulla oblongata and separated from these structures by cavity of fourth ventricle. It is connected to brainstem by three fibre tracts known as cerebellar peduncles. Cerebellum controls the same side of body. It precisely coordinates skilled voluntary movements by controlling strength, duration and force of contraction, so that they are smooth, balanced and accurate. It is also responsible for maintaining equilibrium, muscle tone and posture of the body. This is achieved through the use of somatic sensory information in modulating the motor output from the cerebrum and brainstem. Sherrington regarded cerebellum as the head ganglion of the proprioceptive system. Dysfunction of cerebellum along with degenerative diseases of cerebellum such as spinocerebellar ataxia, multiple sclerosis, malignant tumours, etc. may culminate into disequilibrium, hypotonia, difficulty in talking, sleeping, maintaining muscular coordination and dyssynergia which at times may be life threatening. Hence, knowledge of anatomy of cerebellum is imperative for neuroanatomists and neurosurgeons.

Keywords: cerebellum, pons, medulla, equilibrium, voluntary movements

1. Introduction

Cerebellum is a Latin word meaning little brain. It is the largest part of the hind brain and weighs about 150 g. It is enshrined in posterior cranial fossa beneath the
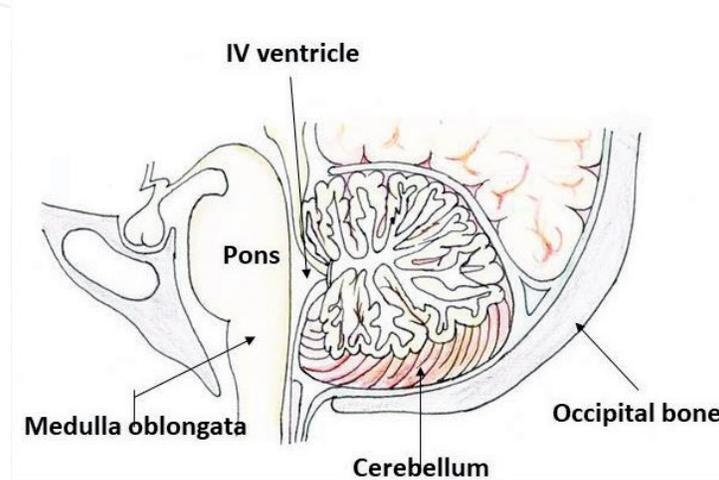
Figure 1.
The location and connections of cerebellum.

tentorium cerebelli behind the pons and medulla oblongata. Cerebellum is separated from the pons and medulla by the cavity of fourth ventricle (**Figure 1**).

Cerebellum is connected to brainstem by three large bundles of fibres called cerebellar peduncles. Superior peduncle connects cerebellum with mid brain, middle with pons and inferior with medulla oblongata [1].

2. Gross anatomy

Grossly cerebellum comprises of three parts: two surfaces, two notches and three well demarcated fissures (**Figure 2A** and **B**).

2.1 Parts

Cerebellum consists of two large bilateral lobes called cerebellar hemispheres. These two lobes are united to each other by a median worm like portion, vermis. Superior and inferior aspect of vermis are known as superior and inferior vermis, respectively. Superior vermis is continuous with the hemispheres but the inferior vermis is separated from hemispheres by deep furrow, the vallecular [2, 3].

2.2 Surfaces

Superior surface of the cerebellum is convex, and two cerebellar hemispheres are continuous with each other on this surface. Inferior surface presents deep furrow known as vallecular which separates two cerebellar hemispheres. The floor of the vallecular is occupied by inferior vermis.

2.3 Notches

There is a wide shallow gap known as anterior cerebellar notch on the anterior aspect of cerebellum. The anterior cerebellar notch lodges pons and medulla. Similarly, posteriorly there is posterior cerebellar notch which lodges falx cerebelli.

2.4 Fissures

Three fissures are related to cerebellum viz. horizontal, postero-lateral and primary fissures.
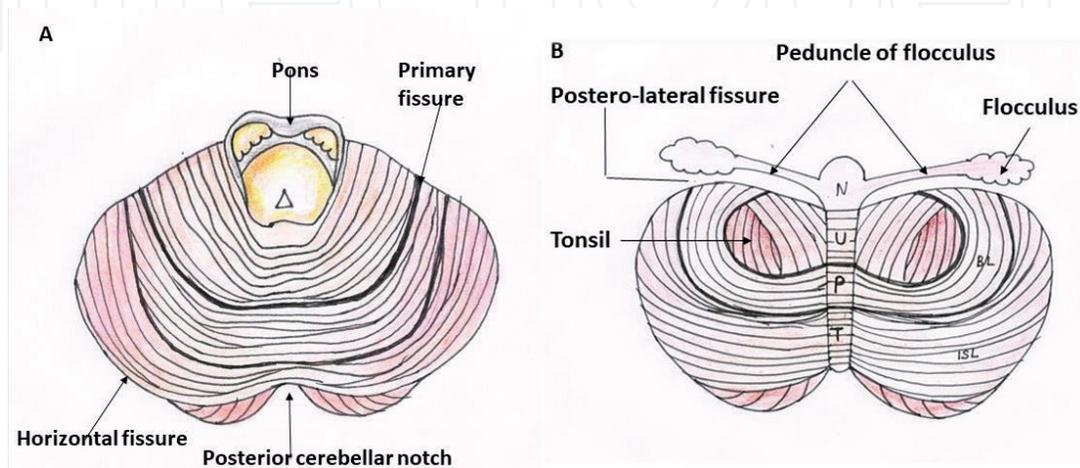
Figure 2.
(A) Schematic diagram showing superior surface of the cerebellum; (B) schematic diagram showing subdivisions of the cerebellum on the inferior surface. N = nodule, U = uvula, P = pyramid, T = tuber, BI = biventral lobule, ISL = inferior semilunar lobule.

Horizontal fissure is most prominent and courses along the lateral and posterior margins of the cerebellum. It separates the superior and inferior surfaces of the cerebellum.

Postero-lateral fissure is located on the inferior surface of the cerebellum and separates the flocculonodular lobe from the rest of the cerebellum also known as corpus cerebelli.

Primary fissure is situated on the superior surface and divides the corpus cerebelli into anterior and posterior (middle) lobes.

3. Subdivisions of cerebellum

3.1 Anatomical subdivisions

Cerebellum is divided by postero-lateral fissure into flocculonodular lobe and corpus cerebelli which is further divided by primary fissure into anterior and posterior lobes.

Flocculonodular lobe is located on the inferior surface in front of postero-lateral fissure and comprises of nodule of inferior vermis and a pair of floccule which are connected to the nodule by peduncles.

Anterior lobe is situated on the superior surface anterior to primary fissure. Vermal portion of anterior lobe consists of lingual, central lobule, and culmen.

Posterior lobe is located between the primary fissure on superior surface and postero-lateral fissure on inferior surface. This lobe includes both surfaces of cerebellum. Superior surface of posterior lobe consists of declive and folium while inferior surface consists of tuber, pyramid and uvula [4, 5].

Subdivisions of vermis and cerebellar hemispheres are described in **Table 1**.

Lobes	Subdivisions of vermis	Subdivisions of cerebellar hemispheres
Anterior lobe	Lingula	No lateral extension
	Central lobule	Ala
	Culmen	Quadrangular lobule
Posterior lobe	Declive	Lobulus simplex
	Folium	Superior semilunar lobule
	Tuber	Inferior semilunar lobule
	Pyramid	Biventral lobule
	Uvula	Tonsil
Flocculonodular lobe	Nodule	Flocculus

Table 1.
Subdivisions of vermis and cerebellar hemispheres.

4. Morphological subdivisions

Phylogenetically cerebellum is divided into three subdivisions: Archicerebellum, Paleocerebellum and Neocerebellum.

Archicerebellum (vestibular cerebellum): it is the oldest part of cerebellum and first to appear in aquatic vertebrates. Fishes and lower amphibians possess only this component of the cerebellum. Archicerebellum comprises of flocculonodular lobe and lingula and has mainly vestibular connections. It maintains equilibrium, tone and posture of trunk muscles.

Paleocerebellum (spinal cerebellum) appears next in terrestrial vertebrates with the appearance of limbs. It includes anterior lobe except lingula and pyramid and uvula. It is concerned with spinocerebellar connections and responsible for tone, posture and crude movements of the limbs.

Neocerebellum (cerebral cerebellum) is the most recent part of cerebellum to develop. It develops in primates and associated with the enlargement of telencephalone and cerebral cortex. It is very prominent in higher mammals. Neocerebellum includes posterior lobe except pyramid and uvula. It is mainly cortico-ponto-cerebellar connections and is concerned with smooth performance of skilled voluntary movements [4, 5].

5. Cytoarchitecture of cerebellum

Cerebellum consists of outer layer of grey matter, the cerebellar cortex and inner layer of white matter. Masses of grey matter, intracerebellar nuclei lie embedded in the white matter. Cerebellar cortex is folded to form narrow leaf like bands called folia. Each folium consists of central core of white matter surrounded by thin layer of grey matter. Central core of white matter is arranged in the form of the branching tree so called arbor vitae cerebelli.

5.1 Grey matter

Main features of grey matter are (a) cerebellar cortex and (b) intracebellar nuclei.

5.2 Structure of cerebellar

Cerebellar cortex composed of three distinct layers: (a) outer molecular layer, (b) intermediate Purkinje cell layer, and (c) inner granular layer cortex (**Figure 3**).

5.3 Molecular (plexiform) layer

This layer consists of unmyelinated nerve fibres derived from axons of granule, stellate and basket cells, dendrites of Purkinje and Golgi cells. It also contains
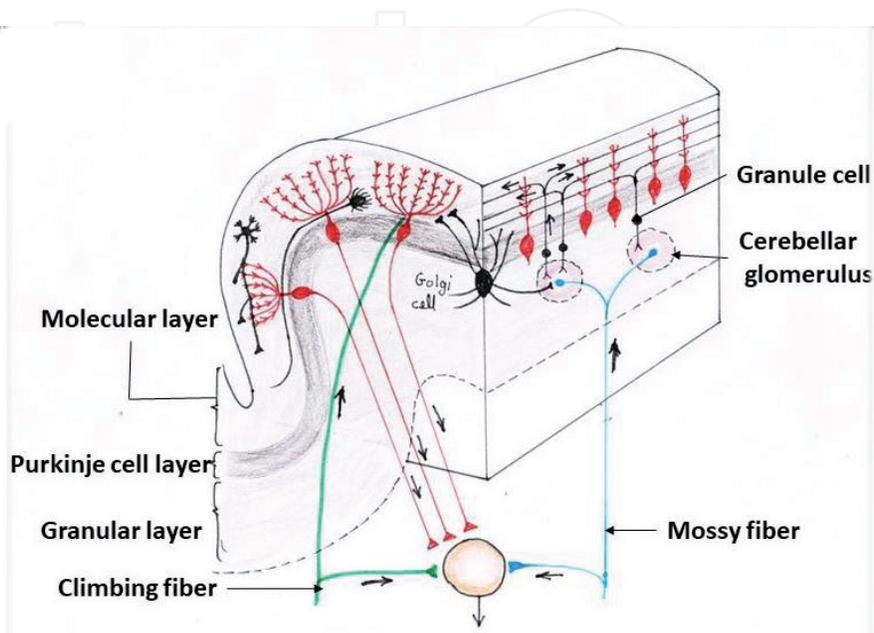
Figure 3.
Structure of cerebellar cortex along with intrinsic neurons and their processes.

stellate and basket cells. Stellate cells possess short process and are found scattered near the surface. The axons of these cell synapse with the dendrites of Purkinje cells. Basket cells contains little cytoplasm but have extensive processes. The axons of these cells follow transverse course parallel to the cortical surface and synapse with dendrites of Purkinje cells.

5.4 Purkinje cell layer

Purkinje cell layer consists of single layer of flask shaped Purkinje cells. Dendrites of these cells travel upwards into the molecular layer in which these cells undergo profuse branching. The dendrites of Purkinje cells synapse with collaterals of basket cells, axons of granule cells and climbing fibres. Axons of Purkinje cells travel through granular layer into white matter where they form synaptic connections with intracerebellar nuclei and exert inhibitory influence on these nuclei.

5.5 Granular layer

The inner granular layer composed of numerous granule cells and few Golgi cells. Each granule cell possesses 4–5 dendrites which synapse with mossy fibres. Axons of these cells courses into molecular layer where these bifurcates and branches pass parallel to the long axis of cerebellar folium. These fibres are known as parallel fibres and synapse with the dendrites of Purkinje cells.

Golgi cells are prominent but scanty, and their dendrites ramify in molecular layer.

Human cerebellum contains about 30–50 billion granule cells, 30 million Purkinje cells and 100 million stellate and basket cells. Purkinje cells, granule cells, stellate cells, basket cells and Golgi cells constitute intrinsic neurons of cerebellar cortex. All intrinsic neurons except granule cells are inhibitory and such collection of inhibitory neurons is not found anywhere in the central nervous system except cerebellum [1, 2].

6. Intracerebellar nuclei

Intracerebellar nuclei (**Figure 4**) also known as central nuclei are collection of grey matter embedded in white matter.

As these are situated close to roof of IV ventricle on each side of midline hence also referred as roof nuclei. From lateral to medial side, these are (1) Dentate nucleus, (2) Emboliform nucleus, (3) Globose nucleus, and (4) Fastigial nucleus.
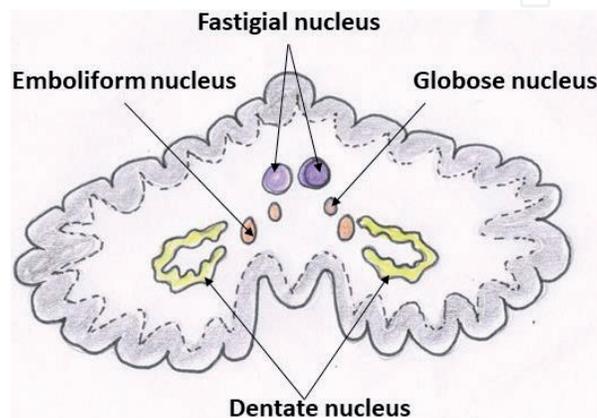
Figure 4.
Intracerebellar nuclei.

6.1 Dentate nucleus

It is the most prominent cerebellar nucleus and largest in primates including human beings. It belongs to neocerebellum and receives afferent from it. Its shape is like crumpled purse with hilum directed ventro-medially and its interior is filled with white matter consisting of efferent fibres forming most of the superior cerebellar peduncle.

6.2 Emboliform nucleus

It is oval shaped and located medial to dentate nucleus. It belongs to paleocerebellum, and this nucleus receives fibres from paleocerebellum and gives fibres to red nucleus via superior cerebellar peduncle.

6.3 Globose nucleus

It is rounded in shape and situated between emboliform and fastigial nuclei. It has similar connections as emboliform nucleus. Emboliform and globose nuclei together are known as nucleus interpositus.

6.4 Fastigial nucleus

This nucleus is situated in the midline in the vermis and smaller than dentate nucleus but larger than nucleus interpositus. It belongs to archicerebellum receiving afferents from it conveying efferents to vestibular and reticular nuclei.

7. White matter

White matter of cerebellum composed of three types of fibres viz. intrinsic, afferent and efferent. Intrinsic fibres are limited to cerebellum and connect different regions of cerebellum either of same hemispheres or of the two cerebellar hemispheres. Afferents and efferents connect cerebellum to other parts of central nervous system.

8. Connections of cerebellum

8.1 Afferent fibres

Cerebellum acquires information from cerebral cortex, spinal cord, vestibular apparatus, red nucleus and tectum of midbrain through afferent fibres. Cerebellum accrues input from cerebral cortex through cortico-ponto-cerebellar, cerebro-olivo-cerebellar and cerebro-reticulo-cerebellar pathways. Cerebellum receives information from spinal cord through anterior spinocerebellar, posterior spinocerebellar and cuneocerebellar tracts and that from vestibular apparatus either directly or after relaying in the vestibular nuclei [4, 5].

Afferent fibres reach the cerebellum through middle and inferior cerebellar peduncle and are of two types: (a) climbing fibres and (b) mossy fibres.

Climbing fibres arises in the inferior olivary nucleus and each fibre after giving a collateral to the intracerebellar nuclei synapses with the Purkinje cell. Mossy fibres are the main afferent fibres of cerebellum, and each mossy divides into 30–40

terminal swellings known as rosette which synapses with dendrites of granule cells and axons of Golgi cells. The structure formed by the rosette along with its synapses with granule and Golgi cells is known as cerebellar glomerulus which is spherical in shape surrounded by a capsule of neuroglial cells.

One climbing fibre synapses with single Purkinje cell; however, one mossy fibre synapses with many granule cells, and each granule cell synapses with thousands of Purkinje cells. Thus, one climbing fibre influences one Purkinje cells while one mossy fibres multitude of Purkinje cells. Both climbing and mossy fibres have excitatory effect on Purkinje cells.

8.2 Efferent fibres

Cerebellum provides output to red nucleus, thalamus, vestibular nuclei and reticular formation through efferent fibres via Purkinje cells. Majority of axons of Purkinje cells synapse with neurons of intracerebellar nuclei which in turn project to other parts of nervous system but few Purkinje cells from flocculonodular lobe and vermis directly end in lateral vestibular nuclei.

Efferent fibres from dentate, emboliform and globose nuclei travel through superior cerebellar peduncle and those from fastigial nucleus through inferior cerebellar peduncle.

9. Intrinsic cerebellar circuitry

All the afferent fibres to the cerebellum viz. climbing and mossy fibres are excitatory to the cells of cerebral cortex, and their collaterals are also excitatory to the intracerebellar nuclei. The climbing fibres excite the Purkinje cells directly but mossy fibres excite the Purkinje cells through granule cells which in turn excite basket and stellate cells but basket and stellate cells inhibit the Purkinje cells. Mossy fibres in addition also excite Golgi cells which in turn inhibit granule cells.

Purkinje cells inhibit intracerebellar nuclei which in turn control muscular activity through motor areas of brainstem and cerebral cortex.

10. Cerebellar peduncles

The afferent and efferent fibres of the cerebellum together form three bundles, cerebellar peduncles on each side. These peduncles are superior, middle and inferior.

Superior cerebellum connects cerebellum to the midbrain, middle to the pons and inferior to the medulla oblongata.

Superior cerebellar peduncle (brachium conjunctivum) ascends upward from the anterior cerebellar notch to the tectum of the midbrain. These peduncles form the supero-lateral boundary of the fourth ventricle. It conveys mainly efferent fibres from the cerebellum arising in dentate nucleus.

Middle cerebellar peduncle (brachium pontis) is the largest of three peduncles and consists principally of afferent fibres to the cerebellum. It bridges the basilar part of the pons and cerebellar hemispheres.

Inferior cerebellar peduncle (restiform body) connects dorso-lateral part of medulla oblongata and cerebellar hemispheres and composed of afferent fibres to the cerebellum from spinal cord, olivary nucleus, reticular formation of the medulla and vestibular nuclei.

11. Fibres transmitted by cerebellar peduncles

11.1 Superior cerebellar peduncle

This peduncle conveys both afferent and efferent fibres.

11.1.1 Afferent fibres

1. Anterior spino-cerebellar tract arise from the cells of laminae V-VII of the spinal cord. This tract convey proprioceptive and exteroceptive impulses from lower limb and lower part of the body and maintenance of posture and movement of lower limb.

2. Tecto-cerebellar tract originate from the superior and inferior colliculi of the midbrain tectum and are projected to the vermal and paravermal regions of declive, folium, tuber and pyramid and carry information from visual and auditory system.

3. Trigemino-cerebellar fibres arise from superior sensory and spinal nucleus of the trigeminal nerve and are projected to the culmen and declive.

4. Ceruleo-cerebellar is nor-adrenergic fibres arising from locus ceruleus and inhibiting Purkinje cells.

5. Hypothalamo-cerebellar fibres are cholinergic fibres originating from hypothalamus.

11.1.2 Efferent fibres

1. Dentato-thalamic fibres arise from dentate nucleus and projected to area 4 and 6 of the motor cortex regulating motor functions.

2. Cerebello-rubral fibres erupt from nucleus interpositus and end in contralateral red nucleus.

3. Cerebello-olivary fibres bud from dentate nucleus and terminate in inferior olivary nucleus.

4. Cerebello-reticular fibres originate from fastigial nucleus and end in reticular nuclei.

11.2 Middle cerebellar peduncle

11.2.1 Afferent fibres

1. Ponto-cerebellar fibres originate from pontine nuclei of basilar part of the pons and projected partly to contralateral neocerebellum and partly to contralateral paleocerebellum. Pontine nuclei receive fibres from cerebral cortex forming cerebro-ponto-cerebellar tract.

2. Reticulo-cerebellar tract arise from reticular formation of brainstem and are projected to the vermal region of the cerebellum.

3. Some serotonergic fibres from raphe nuclei of the pons reach the cerebellum through this peduncle.

11.2.2 Efferent fibres

No efferent fibres pass through this peduncle.

11.3 Inferior cerebellar peduncle

11.3.1 Afferent fibres

1. Posterior spino-cerebellar tract arises from thoracic nucleus (Clarke's column) of the spinal cord conveying proprioceptive and exteroceptive impulses from lower limb to paleocerebellum.

2. Cuneo-cerebellar tract (posterior external arcuate fibres) arise from ipsilateral accessory cuneate nucleus of medulla transmitting proprioceptive and exteroceptive impulses from upper limb and upper trunk and project on culmen and pyramid of vermis.

3. Anterior external arcuate fibres originate from arcuate nucleus of both sides and project into the neocerebellum.

4. Vestibulo-cerebellar tract primarily arise from vestibular nerve and secondary from medial and inferior vestibular nuclei forming juxta-restiform body and projecting to ipsilateral flocculonodular lobe, uvula and lingual. Few fibres end in fastigial nuclei.

5. Olivo-cerebellar tract sprout from contralateral inferior olivary nucleus and project into the neocerebellum but few fibres terminate into deep nuclei.

6. Parolivo-cerebellar tract arise from medial and dorsal accessory olivary nuclei and project on to the contralateral neocerebellum.

7. Reticulo-cerebellar tract buds from lateral and paramedian reticular nuclei of the medulla oblongata and project on to the neocerebellum.

11.3.2 Efferent fibres

1. Cerebello-vestibular fibres sprout from ipsilateral flocculonodular and fastigial nuclei of both sides. These fibres travel through juxta-restiform body and projected to vestibular nuclei

2. Cerebello-reticular fibres arise from fastigial nuclei of both sides and reaches the pontine and reticular formation. Fibres arising from contralateral fastigial nuclei form hook bundle of russel.

3. Cerebello-olivary fibre's origin is unknown and connect cerebellum with the inferior olivary nucleus.

12. Functions of cerebellum

1. Cerebellum maintains equilibrium, muscle tone, posture and coordinates skilled voluntary movements by regulating the grade of muscle tension between agonist and antagonist muscles.

2. Sherrington named cerebellum as the head ganglion of the proprioceptive system as various sensory inputs from the vestibular, visual and auditory systems, stretch receptors of muscle spindle and Golgi tendon organ, tactile and pressure receptors of head and body are relayed in the cerebellum. The sensory impulses are processed in the intrinsic cerebellar circuitry and integrated into the motor system by cerebral motor cortex, red nucleus, vestibular nuclei and reticular formation.

3. If the movement is to be carried out, cerebral cortex sends information to anterior horn cells of spinal cord to initiate movement, and it also sends impulses to cerebellum about the movement to be executed. Cerebellum also receives proprioceptive information from the muscles and joints about the actual movement occurring. The cerebellum compares both these information about movement and if any difference is noted in information concerning intended and actual movement, the cerebellum sends the information to cerebral cortex and anterior horn cells of the spinal cord to correct the discrepancy so that movement carried out is accurate in time, rate, range, force and direction.

13. Arterial supply of the cerebellum

The cerebellum is irrigated by three pairs of cerebellar arteries.

a. Superior cerebellar artery, branch of basilar artery irrigates superior surface of the cerebellum.

b. Anterior inferior cerebellar artery, branch of basilar artery supplies anterior part of inferior surface of cerebellum.

c. Posterior inferior cerebellar artery, branch of vertebral artery irrigates posterior part of inferior surface of cerebellum.

14. Applied anatomy

Cerebellar lesions may occur due to trauma, vascular occlusion, tumour or other pathologies producing cerebellar syndrome. Cerebellar syndrome is grouped in three types viz. Archicerebellar, paleocerebellar and neocerebellar syndromes.

14.1 Archicerebellar syndrome

In this syndrome, predominantly flocculonodular is affected by tumour, medulloblastoma. The patient is unable to maintain equilibrium while standing and falls on closing the eyes. This is called positive Romberg's sign. In addition to this, the patient walks on a wide base with legs well apart and sways from side to side.

14.2 Paleocerebellum syndrome

Lesion of this part of cerebellum produces hypotonia (decreased muscle tone) of limb muscles manifesting as:

a. Instability of joints resulting in flail joints.

b. Abnormal tendon reflex, for example, oscillating movements of leg are produced when patellar tendon is tapped (Pendular knee jerk).

c. Unable to maintain equilibrium while walking exhibiting ataxic gait.

14.3 Neocerebellum syndrome

Lesion in this part of cerebellum leads to incoordination known as asynergia and tremor which manifests in form of:

a. Ataxia due to incoordination of muscles of trunk, pectoral and pelvic girdles. The patient tends to fall on the side of lesion and to prevent fall patient stands or walk on a broad base.

b. Dysmetria culminates into past pointing where the patient is not able to measure the distance for performing intended task. This is tested by finger-nose test in which the patient is supposed to touch the tip of nose by finger but in this disorder the patient either over or under shoots the tip of nose.

c. Intention tremors appear during purposeful movements and disappear during rest. These tremors are coarse, arrhythmic and occur at the end of the movement.

d. Dysdiadochokinesis/adiadochokinesis is the inability to perform alternate movements with rapidity such as supination and pronation.

e. Rebound phenomenon occurs when the action of agonist muscle is not checked by corresponding antagonist muscle. If the patient is asked to push the palm of physician and when physician removes his hand, the hand of the patient moves back (rebounds) and hits the physician as the patient is unable to stop the pushing act immediately.

f. Dysarthria/scanning speech occurs due to incoordination of muscles responsible for speech. The speech is slurred, prolonged, explosive and with pauses at wrong places.

g. Nystagmus results in oscillation of eye ball due to incoordination of extraocular muscles.

In addition to above mentioned diseases, cerebellum is affected by certain neurodegenerative diseases which are elaborated below:
Cerebellar degenerative diseases:

a. **Spinocerebellar ataxia**
This condition involves mutation in genes causing degenerative changes in neurons of cerebellum including brainstem and spinal cord. If a parent is affected by this disease, there is 50% chance of inheriting the disease [6]. It is hereditary progressive degenerative disease often fatal. The disease is associated with progressive incoordination of gait, hand, speech and eye. No treatment is available only symptomatic relief can be provided to affected individuals.

b. **Multiple sclerosis**
In this condition, both genetic and environmental factors influence the outcome of diseases [7]. The myelin sheath enveloping the neurons is damaged resulting in delayed and interrupted impulses from and to the cerebellum [8]. It is incurable condition.

c. **Paraneoplastic disorders**

In this disorder, the person's autoimmune system especially T-cells become active in response to malignant tumours resulting in degeneration of neurons of cerebellum causing impaired ability to talk, walk, sleep, maintain balance and coordinate muscle activity [9]. This disorder is more common in middle aged individuals with lung, ovarian and breast cancer [10].

d. **Chronic alcohol abuse**

This condition is more prevalent in men than women. Chronic alcohol intake reduces vitamin B1 absorption and utilisation leading to degeneration of cerebellar neurons [11]. It is most common cause of nutritional spinocerebellar ataxia.

e. **Parkinson's disease**

Lesions of basal ganglion and cerebellum produce abnormal movements or changes in tone. Tremors occur both with the lesions of basal ganglion and cerebellum. However, tremors in cerebellar lesions occur only during movement, hence also known as intention tremors, while in basal ganglion diseases, like Parkinson's disease, tremors are observed during resting state. In addition to this, other signs of Parkinson's disease like mask face, clasp knife rigidity, lead pipe rigidity and hypokinesia/akinesia are not observed in cerebellar neurodegenerative diseases.

f. **Alzheimer's disease**

This chronic neurodegenerative disease is characterised by gradual onset of dementia. Alzheimer's disease is the cause of dementia in 60–70% cases. Most common early symptom is difficulty in remembering recent events [12]. Later on other symptoms like problems with language, disorientation and mood swings appear slowly. Though the causes of this disease can be various, the risk attributed to genetics is estimated to be around 70% [13]. In this disease, there is degeneration and loss of neurons and synapses in various parts of brain resulting in atrophy (reduction in size) of related regions. Amyloid plaques and neurofibrillary tangles are found deposited in the neurons of the brain [14].

g. **Huntington's disease**

Huntington's disease is also known as Huntington's chorea. It is an inherited disorder caused by mutation in the huntingtin gene which codes for huntingtin protein. Mutant huntingtin gene produces mutant and defective protein which is toxic to neurons of brain causing degenerative changes in brain. This causes problem with mood and mental abilities associated with lack of coordination and unsteady gait. Gradually coordinated movements become difficult and person is unable to talk [15]. There is as no treatment for the disease except for the supportive treatment.

15. Conclusion

Normally, cerebellum maintains equilibrium, muscle tone, posture and coordinates skilled voluntary movements which are very essential to carry out day to day activities. However, lesions of cerebellum may disrupt these actions which may cause various types of inconveniences and discomforts to the patients.

Dysfunction of cerebellum may culminate into disequilibrium, hypotonia and dyssynergia, which at times may be life threatening. In addition to the degenerative diseases of cerebellum described above, it causes difficulty in talking eating, sleeping coordination of muscular activity and other neurological complications. Hence, knowledge of the anatomy of the cerebellum is imperative for neuroanatomists and neurosurgeons.

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