The Cerebellum

This sheet was written according to section 2's recording, some points were also added from section 1's recording and the arrangement of topics might differ a little bit.

Today we'll talk about the second regulator of motor system, the cerebellum.

The location:

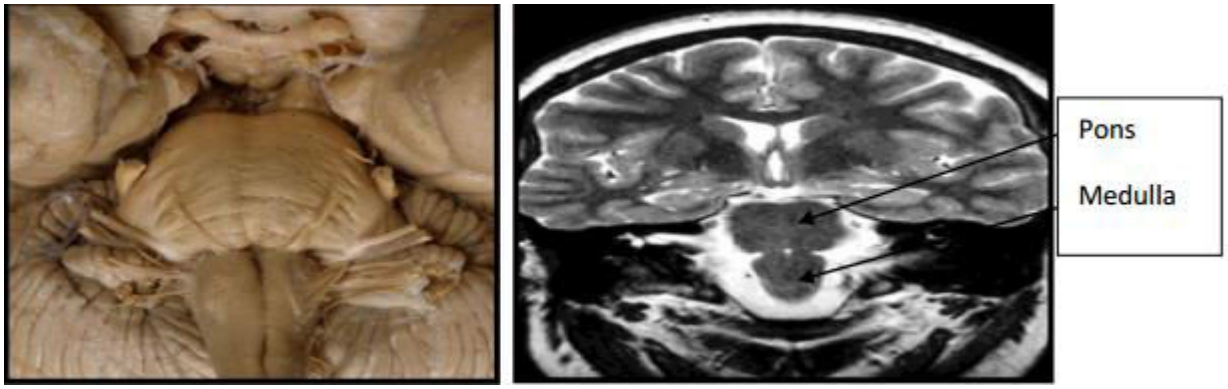
The cerebellum is located posterior to the brainstem, mainly behind the pons.

MRI images of the cerebellum:

► Midsagittal View:

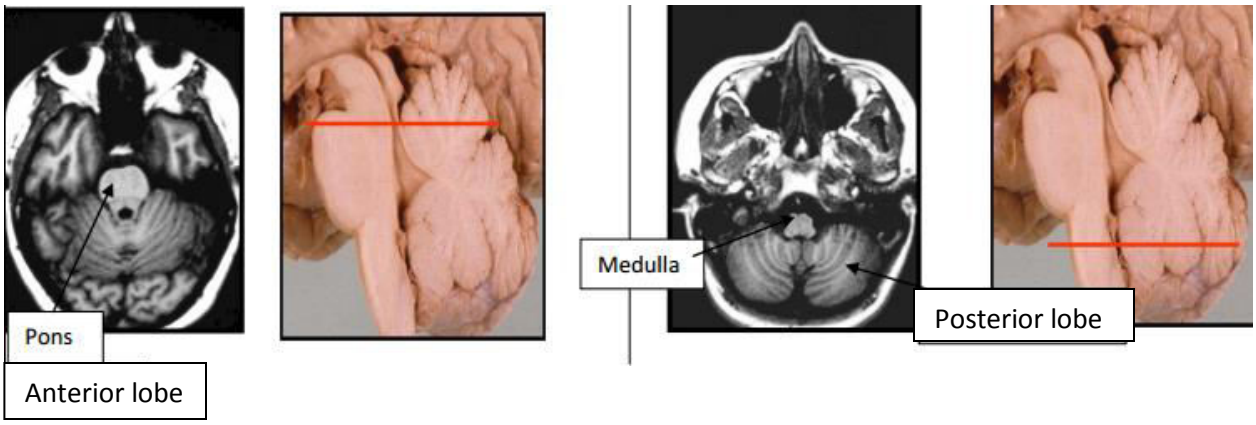
*in a sagittal section to know if it's taken in the lateral side or around the midline you need to look for central (midline) and cortical (lateral) markers; like the corpus callosum which would indicate an almost mid-sagittal section.

►Coronal section:



*in a coronal section you will see a lot of markers as well as the shape of the brainstem.

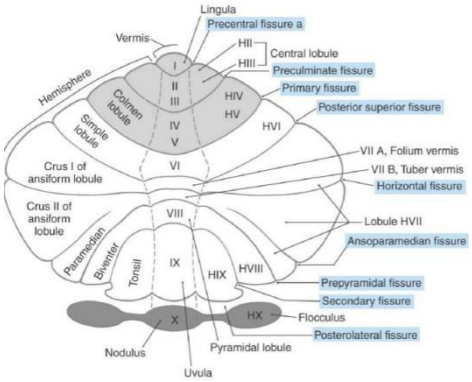
► Superior and inferior horizontal views:



*if you see the pons, this means you will see the anterior lobe of cerebellum and this would be a superior horizontal view. On the other hand, if you can only see the medulla,

then you'll see a part of the posterior lobe of cerebellum and this would be an inferior horizontal view.

Anatomy and Divisions of Cerebellum:



We can divide the cerebellum in two ways:

1) Medial to lateral division:

A- The vermis: most medial part (at midline):

- Connected with the fastigial nuclei.

- Receives proprioception input from the dorsal columns of the spinal cord and the trigeminal nerve, as well as from visual and auditory systems (Wikipedia).

- Concerned with the trunk and proximal muscles

- We call the Vermis + Paravermis → spinocerebellum

B- Paravermis (intermediate zone):

- Lateral to the vermis and medial to the hemisphere.

- Connected with the interpositus nuclei (emboliform and globose nuclei).

- Receives climbing fiber input from the inferior olive.

- Concerned with the distal part of limbs (hands, arms & feet)

C- Lateral parts of the cerebellar hemispheres:

- Connected with the dentate nuclei.

- Connected directly to the cortex →

1) Association cortex: hence its relation to depression, behavior and psychiatry.

2) The premotor and supplementary motor parts of the frontal cortex: responsible for skilled movement/fine movement which will be affected in case of lesion to the lateral part.

2) Anterior to posterior division:

A) Anterior lobe →

-Divided into lobules numbered from (1-5).

-Mainly concerned with motor input and proprioception, this usually comes directly through the spinal cord.

-Composed mainly of vermis and paravermis (spinocerebellum).

B) Posterior lobe→

- Divided into lobules numbered from (6-9).

- Mainly concerned with the brainstem, cortex and subcortex/Hypothalamus (esp. the medial part/vermis)

C) Flocculonodular lobe→ the 10th lobule.

Notes:

1-The more medial you go in the division, the more medial part of body it represents.

2- Moving from anterior to posterior, the representation of body parts is rostral to caudal.

The cerebellar connections:

The cerebellum is connected to the cerebral cortex through direct and indirect connections (through the pons). We won't discuss the direct connection because it's complicated, but we will discuss the connections through the pons.

REMEMBER: the connections between the cerebellum and the cortex are contralateral BUT another crossing occurs after leaving the cortex so we end up with ipsilateral relation between the cerebellum and the body (Except in the visceromotor (vesiculomotor) pathways which control blood pressure, heart rate and other things related to viscera, which act bilaterally).

Input to the cerebellum:

It receives input either directly such as sensations that have spinal reflexes; like pressure and proprioception (through the spinocerebellar tract). Or indirectly such as the vestibular input which will be processed in the association cortex (association of vision and hearing).

Output from the cerebellum:

Part of the output passes to the unconscious part of the motor system (extrapyramidal tract in the brainstem) and continues through the spinal cord. Another part would reach the thalamus and continue to the neocortex; especially motor cortex to adjust the motor output if needed.

The main functions of cerebellum:

1) Maintaining Body equilibrium

2) Regulation of muscle tone

3) Coordination of movements→

It coordinates between sensory and motor functions to get the desired motor output (the best result) by:

1) Comparing the sensory input with the desired motor output.

2) Making the required adjustments to achieve it.

Once we've achieved it, the cerebellum will store the motor program so the next time we do the same action, it will follow the stored program and adjust the motor orders accordingly so that we'll achieve our goal again.

Functions of Cerebellum VS Basal ganglia:

If you want to do a simple movement for example flexion of the elbow followed by extension, the orders would come from the cortex to contract the biceps and relax the triceps → flexion, and then vice versa (relax the biceps and contract the triceps) →extension. The orders coming from the cortex will be partially processed in the basal ganglia (they will decide which to stimulate and which to inhibit). But when it comes to complex movements (sequences of movement), the timing of contraction and relaxation of muscles requires balance of what we need to do and what sensation we have, which will be done by cerebellum.

**The sequence and time manner of pausing that come from learned skilled movement is one of the functions of cerebellum.

#Like The basal ganglia, the cerebellum processes intended orders from all parts of cortex, so all parts of the cortex are connected to it. The cerebellum, especially the lateral part (lateral posterior more than lateral anterior) is heavily connected with the association cortex like the prefrontal cortex. The intentions of the cortex and the unconscious memory of the action are normally checked by the cerebellum, this explains how lesions of cerebellum can be associated with non-motor functions and changes in behavior or intention.

Note:

The basal ganglia and the cerebellum work together (at the same time) to coordinate movement. To differentiate between them, we can say that the **basal ganglia** work **before the action** and the **cerebellum works during it.**

Principles of Function of cerebellum:

The cerebellum works in a feedback and feedforward mechanisms or circuits, by acting as a:

1) Comparator. 2) Storage for information. 3) Timing device.

● This will be explained later in the sheet.

► We'll start with the feedback circuit.

Feedback circuit:

Let's say for example you wanted to hold an egg, your goal is to hold it correctly, not drop it or crush it with your fingers. So you need balance between your sensory input (proprioception + pressure sensation on your fingertips) and your motor output (degree of muscle contraction in your hand). This balance is achieved through the cerebellum; which will continuously adjust the motor output in order to get the appropriate degree of muscle contraction in response to the sensation you have at that moment.

If this was your first time holding an egg (no previous experience like in early childhood), you might hold it with too much force, which will increase the pressure on your fingertips → sensory input, and this in turn will increase the motor orders from the cortex (muscle contraction → motor output) and you might break the egg with your fingers. On the other hand, you might hold it lightly so there won't be enough pressure on your fingertips (sensory input), and the muscle contraction in your hand (motor output) won't be enough to hold the egg so you'll end up dropping it.

So the first time you tried to hold it, the egg fell and the goal was not achieved (the experience). So the next time you want to hold an egg, the cortex will send the same orders (motor output) but now the cerebellum will send feedback to the cortex asking it to increase the muscle contraction, but the pressure applied on the egg by the muscle contraction might be too much and you would break it. Time after time, by trial and error the cerebellum will keep adjusting the orders until you get the perfect coordination and you would hold the egg correctly. It will then keep checking the orders every time you want to do the same action. (Feedback is happening at the same time as the action to get the best result).

So it's a learning process and once you've learned it, it will be stored in your cerebellum forever and you'll be able to hold the egg correctly for the rest of your life.

Note: The cerebellum works as a comparator, as it constantly compares the desired output with the actual output, and makes adjustments during the execution of the movement until the actual movement matches the desired movement.

Feedforward circuit:

●Example (1):

If you throw an apple to your friend and he tries to catch it, he would see the apple coming through the primary visual cortex and the association cortex will calculate the speed, distance and direction of the apple and determine its position after a certain amount of time (the interval), so The cerebellum, will receive the information coming from the association cortex and check the order coming the motor cortex (the intended movement) and will adjust it over and over again according to experience and repetition so that the motor function would come out as planned and he would catch the apple at the right time. This is called the "feedforward circuit" (the cerebellum would adjust the order based on prediction for sensation i.e. before the actual execution of movement).

►This mechanism is mostly observed in basketball players; by practicing how to throw the ball exactly through the hoop, after continuous practice the player would adjust his motor output (how strong and fast he needs to throw the ball) so it would enter the hoop every time.

●Example (2):

In an experiment done on some professional basketball players, they were asked to wear special glasses with lenses that shift the vision, for example it would shift the vision 20 cm, i.e. if something is present at a certain point, the person wearing the glasses would see it 20 cm shifted from its original site. For the first five minutes, the players would throw the ball 20 cm away from the hoop (because the glasses would make them see the hoop at that place *20 cm away from its original place*) so they wouldn't score. And with

continuous learning, the cerebellum would adjust the balance between the intended motor order and visual information (which is distorted due to the lens) so that the players would start aiming the ball 20 cm away from the distorted site of the hoop (the site they see according to their distorted vision) i.e. they would aim at the real hoop and they will be able to score.

The same thing would happen if they take the glasses off, for the first 5-10 minutes, they would miss the hoop until the cerebellum is able to adapt and correct the orders again so that they would score. (Feedforward adjusts intended movement "before it happens").

Note: The cerebellum works as a timing device, so that it would enable us to do learned skilled movements through previous experiences. It guides and coordinates movement depending on the direction and target of the movement by regulating the timing of motor output.

Note:

Both circuits need storing of the information (memory), so that it could use the previous experience of what was successful and what wasn't, the storing and processing happens in the biggest cells which are the Purkinje cells.

#In general we can say that the feedback loop is for the sensation that requires reflexes; like proprioception, sensations coming through the spinal cord and the vestibular input (unconscious information). Whilst the feedforward loop is for the sensations that are processed through the cortex where the prediction is done (learned behaviors).

***There are two types of memory in the CNS:**

1) Conscious type of memory; which is processed and stored in the cortex.

2) Unconscious type of memory; which is mostly stored in the cerebellum. It has two types: A) motor memory/motor learning, B) non-motor memory; example: the classical conditioning.

►Classical conditioning (Pavlov's trials): it indicates the repetition of response on repeated stimulus. In the trial Pavlov rang a bell before serving food to his dogs, and the next time he rang the bell, the dogs started drooling, because they could predict what would happen (food would be served).

Circuits within the Cerebellum:

The doctor said that the circuits inside the cerebellum are not important, you only need that the main type of cells in the cerebellum are **purkinje cells** -they are responsible of processing and storing information-.

"If you read this topic from any source you'll find information about the cells, the layer, the fibers and which ones are excitatory and which are inhibitory. You don't really need to know all that for your clinical years."

Purkinje cells release GABA neurotransmitters, so anything affecting the GABA neurotransmitters will affect purkinje cells and consequently affecting the functions of cerebellum. (Most common effector on GABA neurotransmitters is alcohol)

NOTE: The modulatory neurotransmitters from the brain stem (the biogenic amines, mainly dopamine, serotonin and norepinephrine) send modulation to both the cerebral cortex and the circuits inside the cerebellum.

The motor functions of the cerebellum:

The cerebellum controls both conscious and unconscious movements and reflexes by comparing the sensation with the motor orders sent from the cortex, and corrects the motor orders to achieve the desired action (target) according to the sensation.

Any lesion in the cerebellar functions leads mainly to **ataxia**.

► **Ataxia**: is loss of coordination of movement and sensation so the patient won't be able to achieve the target, we talked about the sensory ataxia and now we are going to talk about cerebellar ataxia.

Cerebellar ataxia: it's associated with several clinical presentations such as:

1) Loss of balance and ataxic gait (Disorders of equilibrium):

A lot of reflexes control the equilibrium to achieve the good posture and balance such as the extrapyramidal tract and the vestibular system.

Normally there is coordination between the sensation and the motor orders, so with any deviation from the body axis the vestibular system in association with the cerebellum will sense it and try to avoid falling by sending orders to maintain balance.

BUT in the case of cerebellar ataxia the cerebellar activity is absent so the cerebellum won't be able to check or correct the orders coming from the vestibular system and it will be easier to lose balance and fall down with any small deviation. Also the posture will be affected because the patient will be always worried that he'll fall so he will try to stand in way that keeps the shaking at its minimum (which is by separating his two feet), and he will walk in a way that minimizes the head movement to maintain body balance (ataxic gait).

►The cerebellar ataxia can be tested easily by making the patient walk in a straight line **heel-to-toe (tandem walking test)** and this test is used by the police to check if the person is under the effect of alcohol or not.(the person won't be able to walk heel-to-toe if he has cerebellar defects or under the effect of alcohol).

2) Intention tremor and Dysmetria:

Normally if a person wants to touch something that is 1.5 meters away for example, the vision centers will send information to the cerebellum, which in turn sends orders to the motor cortex, and the person will extend his arm and tilt his trunk a little bit to reach his target. But in the case of cerebellar ataxia the patient won't be able to reach his target from the first trial due to loss of coordination between visual sensation and motor orders, so he will break the movement into segments (repeat the action several times) until he reaches his target and this is related to dysmetria, which the inability to measure distances

correctly. Also his hand will shake increasingly as he approaches the target; this is called "intention tremors".

► We test the intention tremor using the **finger-to-nose test**. In a finger-to-nose test, a physician has the individual touch his nose with his finger, an individual with intention tremors will have coarse shaking movements that increase in severity as the finger approaches the nose.

Rest Tremor V.S Intention Tremor:

In severe cases of cerebellar disease, if the doctor asks the patient to extend his arm and it starts shaking, this is considered "Intention Tremor". That's because extension of the arm is a movement against gravity that requires a balance between the muscle contraction and the weight of the arm (Force of gravity), which is normally done by cerebellum. In cases of cerebellar disease there would be a deficit in the balance, hence the tremor. On the other hand, if the patient was resting and his hand was shaking, this is considered "Rest Tremor" associated with Parkinson's disease, unlike the tremor that happens upon extending the arm (movement → intention tremor which would not be present at rest). The main difference between Intention and Rest Tremors is that Intention Tremor is rarely -almost never- associated with behavioral changes because it happens due to cerebellar disease (we're mostly concerned with cognitive decline and dementia which are associated with Parkinson's disease).

Intention tremor, which appears most commonly in older ages, has a familial type which is called "Essential Tremor" that could worsen with time. Essential tremor happens due to degeneration of neurons in the cerebellum itself, or due to a deficit in the modulators that affect the cerebellum. In both cases, the function of the cerebellum would decrease with time and the patients at older ages would have tremor.

→Now let's continue with the clinical presentations of cerebellar ataxia:

3) Dysdiadochokinesia: patients won't be able to perform rapid, alternating movements and this because the post-learning activities are stored in the cerebellum. I.e. the patient won't remember the sequence of moves.

4) Dysarthria: This is often characterized by slurred or slow speech that can be difficult to understand.

►Patients with cerebellar ataxia won't suffer from aphasia, which is associated with cerebral lesions.

Aphasia: is an impairment of language, affecting the production or comprehension of speech and the ability to read or write.

5) Nystagmus: It won't appear if the patient isn't moving his eyes, but if you ask him to follow the movement of your finger you'll be able to notice the nystagmus.

Non-motor cerebellar functions:

These usually happen in association with motor functions. Example of non-motor functions are the visceromotor problems which are more prominent with motor problems i.e. When the physician runs some motor tests on the patient like the finger-to-nose test (a test for intention tremor), as the patient starts moving his finger he would start showing visceromotor signs like dilated pupils, flushed face and his body's temperature would go up.

Visceromotor Functions:

These happen because of loss of good control over the unconscious parts of our body like the visceral system, so the patients would have:

1-Dilated pupils.

2-Flushed face and increased sweating.

3-Decreases in heart rate and blood pressure.

4-Executive, visual-spatial, linguistic and affective deficits (mainly 7^{th} and 8^{th} lobules in the posterior lobe).

5-Mutism (inability to speak in a certain situation or associated with a certain emotion) and impaired verbal fluency.

6-Affective symptoms and personality changes (Aggression and irritability)

7-Attentional and emotional problems (depression or complete psychiatric disorders probably due to problems in the posterior lobe).

NOTE: The difference between lesions in cerebellar cortex and cerebellar nuclei is that the cortex is usually adaptable i.e. it has plasticity more than the nuclei. So lesions to the cortex are usually short term, afterwards it gets better. Ex: a neurosurgeon suffered from a stroke in the cerebellar cortex, 2 months later he was able to practice again. On the other hand, lesion to the nuclei is almost permanent.

Thank you.

당신이 이해하지 않는, 어떤

Dedicated to "THE SQUAD".