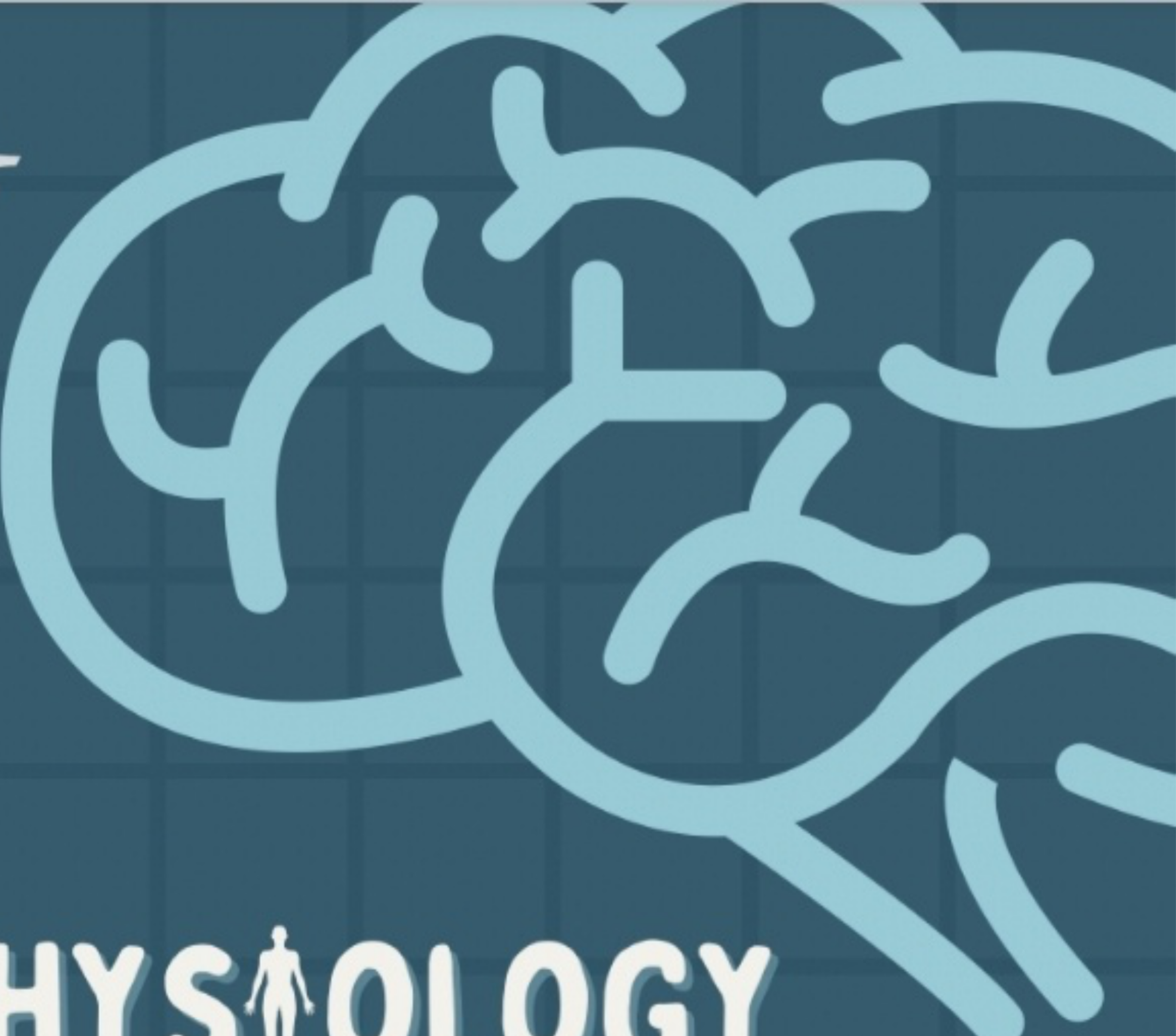


PHYSIOLOGY

SHEET NO. 9

WRITER : Doctor 018

CORRECTOR : دانيا أبوجودة
إيثار ابوساره

DOCTOR : Faisal Mohammad

Motor system – Motor of the spinal cord

Quick Revision

Before we start talking about the motor function of the spinal cord, let's first take a quick look at the motor system and the incredible connections taking place inside it:
[please refer to the pictures for better understanding]

1- Motor command

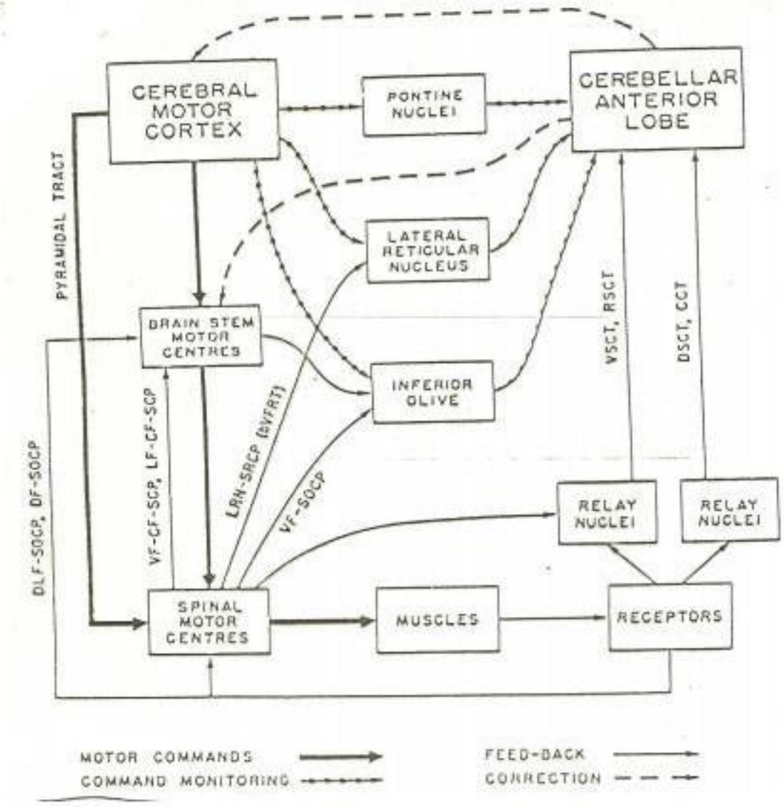
For any motor function (movement) to occur, the nervous system has motor command that comes **from the cerebral motor cortex to the spinal cord** and these descending tracts (**corticospinal**) are called also **pyramidal tracts** and that's because they pass through the pyramids of medulla oblongata.

The neuronal fibers coming from the cortex ending in the spinal cord are considered **upper motor neurons**, while the neuronal fibers going out from the spinal cord to reach the muscles are called **lower motor neurons**.

There are other origins for the motor commands such as the brain stem and the red nucleus that send neuronal fibers to the spinal cord in order to control the activity of the muscles.

2- Motor command intension

At the same time, there are some tracts going from the cortex to the cerebellum through the brain stem like the corticopontocerebellar, corticoreticulocerebellar, corticolivarycerebellar tracts. And these tracts are telling the cerebellum about the intended movements. (= the movements we want to do)



3-motor command monitor/ feedback system

a- Inside the muscles we have receptors (**muscle spindles/ stretch receptors**, **Golgi tendon organs**) that are connected to sensory (afferent) neuronal fibers that goes to the spinal cord relay nuclei.

b- From the spinal cord they go to the cerebellum through **ventral and dorsal spinocerebellar tracts** to tell the cerebellum what is exactly happening down at the level of the muscles.

c- Then the cerebellum will do its job and send orders through the (ventroanterior **VA** and ventrolateral **VL** parts) to the cerebral cortex to monitor the motor commands.

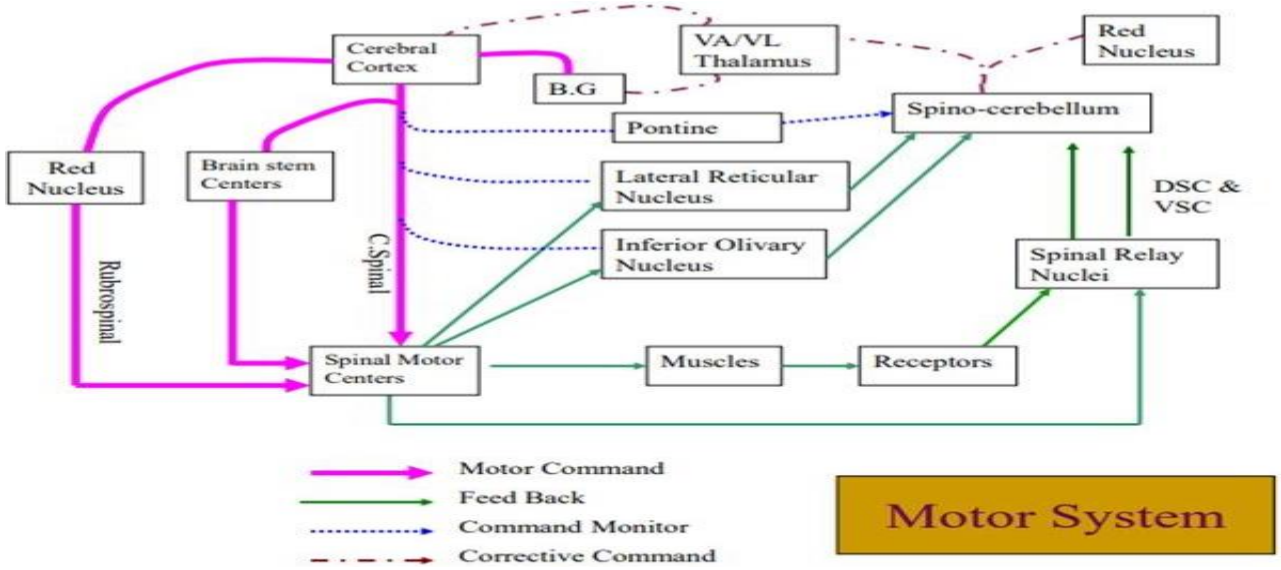
[receptors -> spinal cord -> ventral and dorsal spinocerebellar tracts -> cerebellum -> thalamus VA/VL -> cerebral cortex]

Remember that the sensory (ascending) tracts go to the cerebral cortex through the ventral basal complex (VPL, VPM) of the thalamus.

d- Feedback can also be through **inferior olivary nucleus** and lateral reticular nucleus

4-Correction process

What will the cerebellum do with this information? It **compares** motor command intension with motor command monitor/ feedback system to see if they meet or not. And if they don't meet, the cerebellum will send orders to the cerebral cortex to correct it.



Why all of this is happening ? Usually the cerebral motor cortex doesn't send exact signals to the spinal cord (corticospinal tract), it sends either more or less than what is intended, so the muscles react more or less than what is intended. The cerebellum will know what is going on the level of the muscles (motor command monitor) and what is the movement we were trying to do (motor command intension) and is going to correct it by sending orders to the cerebral motor cortex through the thalamus [the secretary of the cerebral cortex]. This correction process is **continuous and very fast**, we don't feel that the muscle movement is hectic [having tremors –> *intention* tremor].

➔ We can say that if the *movements* come from the cortex without the correction and the monitoring from the cerebellum, they *will be pendular* [= with a lot of tremors], and that's what exactly happens *when there is disease or damage of the cerebellum.*

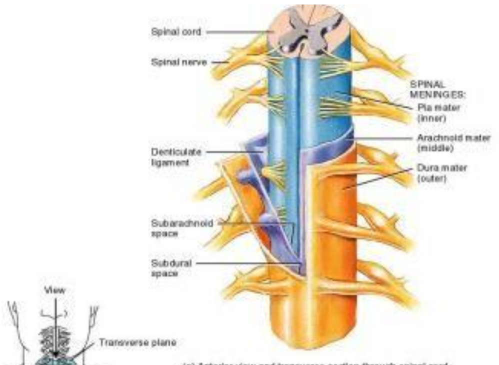
Lecture starts here

* After this heavy introduction, we reached to the easy part in this sheet – motor function of the spinal cord

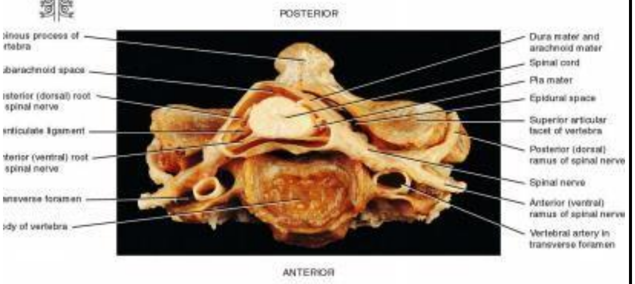
The Spinal Cord is More Than Just a Conduit for Nerve Fibers

The spinal cord is the lowest part of this motor system, it is a pathway for the nerve fibers, Neuronal circuits for walking and various reflexes. And from the introduction we noticed that higher brain centers activate and command these circuits.

What we should know is that <u>we can use the same circuit for more than one function,</u> because we don't have a lot of circuits, the same circuit used for walking can be used for maintaining equilibrium [anti-gravity muscles/ extensors] and for other functions like reflexes.



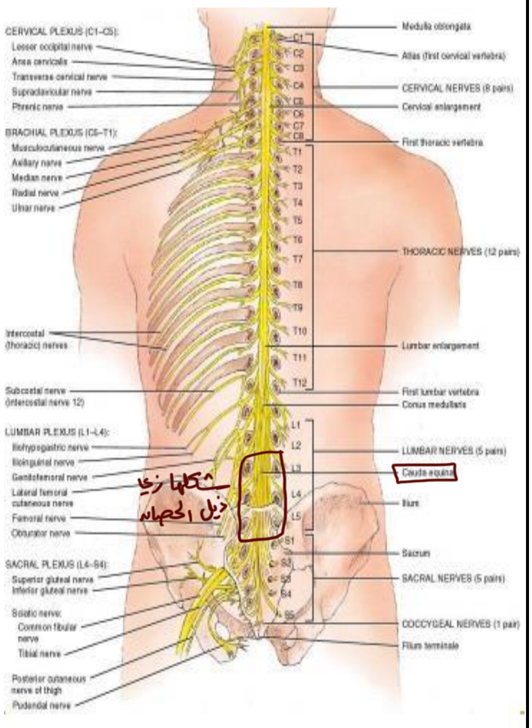
(a) Anterior view and transverse section through spinal cord



(b) Transverse section of the spinal cord within a cervical vertebra

- The spinal cord consists of 31 segments (8 cervical, 12 thoracic, 5 lumber, 5 sacral, 1 coccygeal). From each segment, there is a pair of spinal nerves (right and left) coming out from the intervertebral foramen.
- The spinal cord is so delicate structure but has a hard covering (vertebral column).
- Because the bony tissue grows faster than the neural tissue, spinal cord ends at the level of L1/L2 vertebrae. Below this level, where is no spinal cord, there are nerves coming from higher spinal cord segments forming a structure called ذيل **cauda** حصان **equina**.
- The Spinal cord is covered with the meninges: dura matter [close to the vertebral column/ hardest], arachnoid matter and pia matter [close to the spinal cord].
- Between the arachnoid matter and pia matter is the subarachnoid space filled with CSF. To collect a sample of this fluid, we do a lumber puncture below the level of L1/L2 [usually at the level of L4/L5].

  CSF is produced in the ventricles by the choroid plexus and absorbed by the arachnoid villi. We have 4 ventricles: 2 in the left and right hemispheres called lateral ventricles -lateral ventricles -> 3rd ventricle -> 4th ventricle ->the central canal of the spinal cord.



Posterior view of entire spinal cord and portions of spinal nerves

Internal Anatomy of Spinal Cord

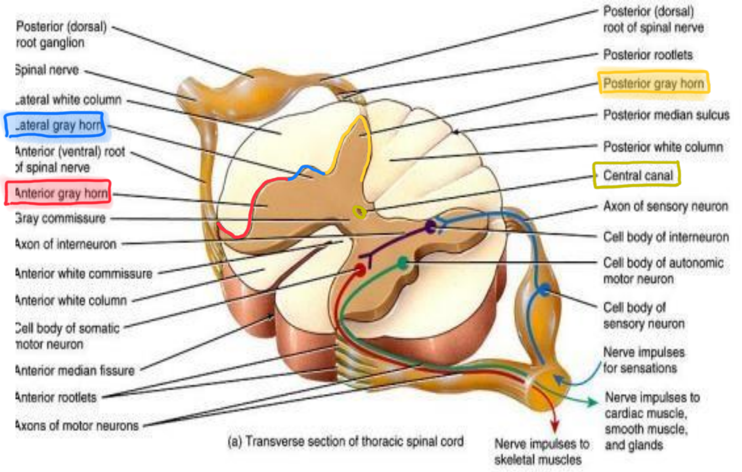


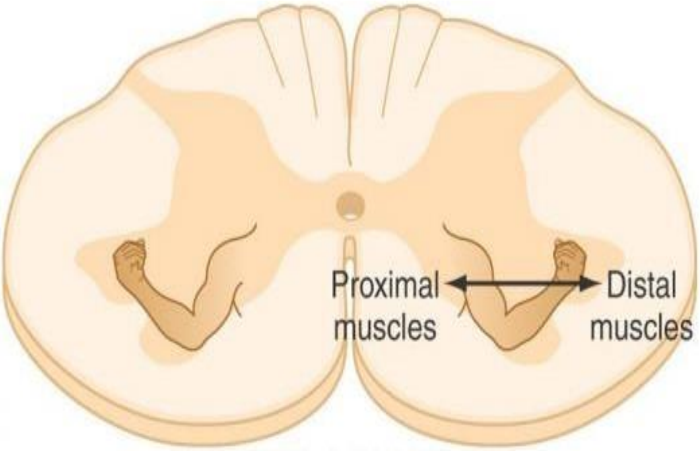
Figure 13.03 Tortora - PAP 12/e
Copyright © John Wiley and Sons, Inc. All rights reserved.

Inside a spinal cord segment, we can find an anterior median fissure and a posterior median sulcus dividing the segment into right and left part. The H- shaped gray matter in the middle of the segment is divided into anterior, posterior and [in some segments especially thoracic] lateral horns. The gray matter is a collection of neuronal cell bodies and dendrites. And the central canal with its CSF in the center of the segment.

Around the gray matter, we find the white matter consisting of columns (2 posterior, 2 anterior and 2 lateral). The white matter is a collection of myelinated axons. 2 = right and left

Sensory neurons have their cell bodies in the dorsal root ganglia, they enter the spinal cord through the dorsal root and synapse in the dorsal horn with interneurons. Interneurons synapse with motor neurons going out from the spinal cord through the ventral root to the effectors (skeletal muscle, gland, smooth muscle (ANS)).

Remember that **tract** is a collection of neuronal axons in the CNS and **nucleus** is a collection of neuronal cell bodies in the CNS . While a **nerve** is a collection of neuronal axons in the PNS and **ganglion** is a collection of cell bodies in the PNS.



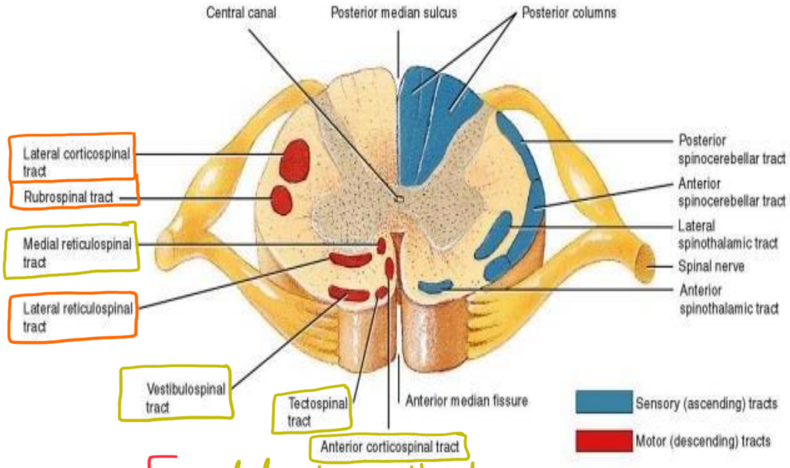
B

(Redrawn from Purves D et al(eds): Neuroscience, 3rd ed. Sunderland, MA, Sinauer, 2004.)

We studied a lot about the amazing organization of the CNS, and this is applied on the motor system too, the spinal cord motor system has a very ***organized structure*** that if one area isdestroyed, one muscle might be affected only.

We can find the neuronal cell bodies of the proximal [axial] muscles in the medial part of the gray matter, and the distal muscles in the lateral part.

In the picture to the right, you can find all the sensory [ascending] tracts, we are concerned here with motor [descending] ones. We have **the lateral system tracts** consisting of **the lateral corticospinal tract** [crossed] and **the rubrospinal tract** [from the red nucleus in the midbrain], both tracts excite the flexors and inhibit the extensors. Other tracts are the **lateral reticulospinal tract** from medulla oblongata, **medial reticulospinal tract** from the pons, **vestibulospinal tract** and **tectospinal tract** coming from the tectum.



The tectum has:

excite flexors
inhibit extensors ← [medial system pathway
lateral system pathway.

1. 2 superior colliculi [for vision] which moves the head in response to light.
2. 2 inferior colliculi [for hearing] which moves the head in response to sounds.

Motor Organization of the Spinal Cord

- The Sensory fibers enter the spinal cord and are transmitted to higher centers [ascending tracts], or they synapse locally to elicit motor reflexes. [will be discussed later]
- Motor neurons are located in the anterior portion of the spinal cord.
- motor neurons are 50 - 100 % bigger than other neurons.

Anterior Motor Neurons [lower motor neurons]

Any muscle has two types of fibers: extrafusal fibers responsible for the contraction of the muscle and intrafusal fibers related to muscle spindles (stretch receptors).

There are two types of lower motor neurons:

1- Alpha motor neurons: give rise to large **type A alpha** fibers (~14 microns).
   - stimulation can excite 3 - 100 **extrafusal** muscle fibers collectively called a motor unit. Motor unit: the motor neuron and the muscle fibers it supplies.
2- Gamma motor neurons: give rise to smaller **type A gamma** fibers (~5 microns),
   -stimulation excites **intrafusal** fibers, a special type of sensory receptor.

Interneurons and Propriospinal Fibers

Interneurons: 30 times as many as anterior motor neurons, small and very excitable, comprise the neural circuitry for the motor reflexes. Most of the neurons in any segment are interneurons.

Propriospinal fibers: travel up and down the cord for 1 - 2 segments, provide pathways for multisegmental reflexes. They connect segments together. for intersegmental integration

Sensory Receptors of the Muscle

There are two types of **receptors** in muscles:

1- **Muscle Spindle**
   sense muscle length and change in length and rate of change in the length [***prediction***]
2- **Golgi Tendon Organ**
   sense tendon tension and the change in tension

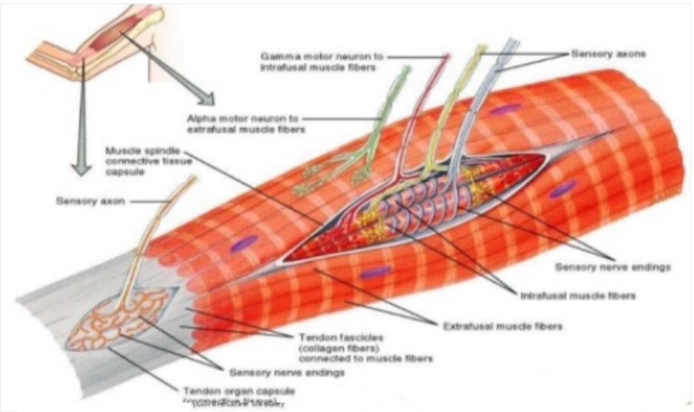
Tension refers to the increase in the length of the muscle.

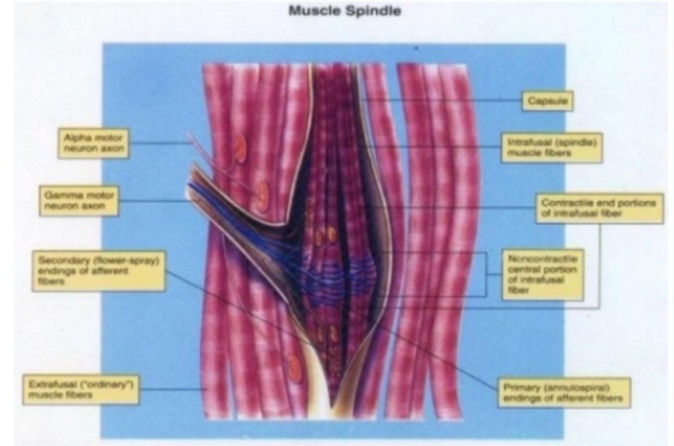
These receptors sense the tension and the rate of change in tension, some of them are **static** [length] and some are **dynamic** [rate].

The density of the receptors is proportional to the importance of the signals/ information they collect. Important sensations have a high density of receptors. Muscles that are used most often like muscles working against the gravity (antigravity muscles) have a lot of muscle spindles and Golgi tendon organs.

Now let's talk about the structure of the muscle spindle:

- ✓ Muscle spindle consists of capsule, stretch receptor and intrafusal fibers.
  It is almost non-contractile except for small regions in the two peripheries that are contractile.
- ✓ The non-contractile (sensory) part is present in the center of the muscle spindle and is supplied by **sensory neurons** while the contractile part is present in the periphery of the muscle spindle and is supplied by **gamma motor neurons** (static and dynamic).
- ✓ Two types of muscle spindles exist: **the nuclear bag form** where the nuclei of the muscle fibers are organized in the core in a shape like a bag and **the nuclear chain form** where the nuclei of the muscle fibers are spread along the whole length of the muscle spindle.

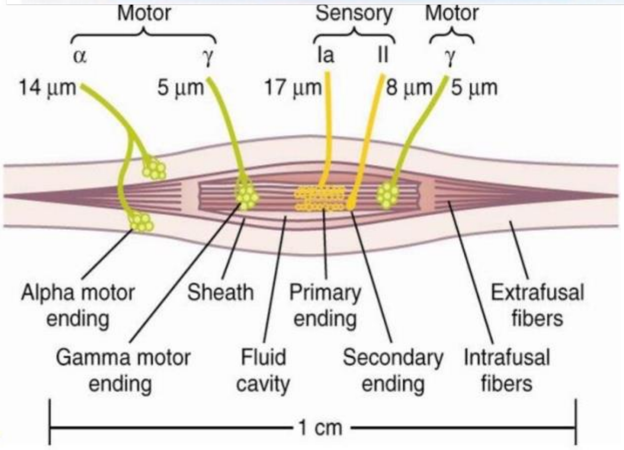




- ✓ Each type is supplied as we said by **sensory neurons**.
  - The nuclear bag fiber is supplied with **group 1a fibers** (large myelinated) which are considered **the primary afferent fibers** (called annulospiral) and **dynamic**.
  - **The nuclear chain fiber** is supplied with **group 2 fibers** which are considered **secondary afferent fibers** (called flower-spray) and **static**. [it is supplied also by primary afferent fibers]

✓ There are two ways to activate a muscle spindle (stretch receptors):

1- Any stretch in the muscle that lengthens it will stimulate the center of the muscle spindle.
2- Activation of gamma motor fibers will contract the contractile parts of the muscle spindle stimulating and keeping it stretched.



Static Response of the Muscle Spindle

When the center of spindle is stretched slowly - the number of impulses generated by the primary and secondary endings increases in proportion to **<u>the degree of stretch</u>**. This is the 'static response'.

Function of the static nuclear bag and nuclear chain fibers.

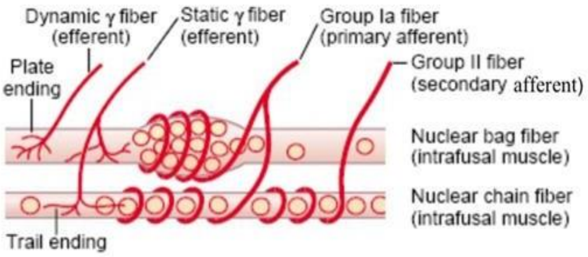


Figure 54–3

Details of nerve connections from the nuclear bag and nuclear chain muscle spindle fibers. (Modified from Stein RB: Peripheral control of movement. Physiol Rev 54:225, 1974.)

Dynamic Response of the Muscle Spindle

When the center of the spindle is stretched rapidly - the number of impulses generated by the primary endings increases in proportion to **<u>the rate of change of the length.</u>** This is the 'dynamic response'.

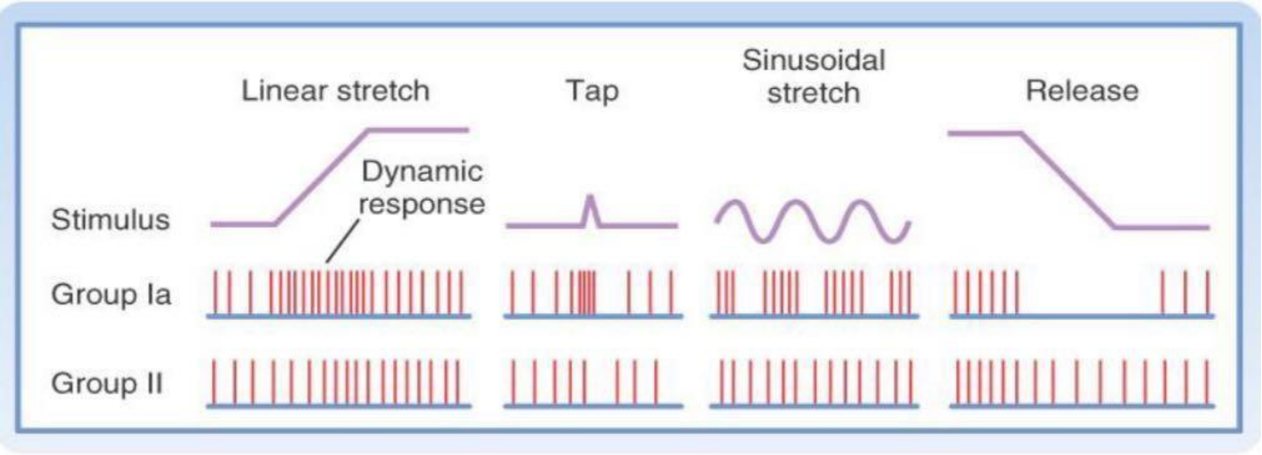
function of the dynamic nuclear bag fiber ONLY.

Why is it important to sense the rate (speed) of the change of the length?

When our nervous system knows the rate (speed) of change of the length and the distance we want to go through, it will calculate the time predicted to cut this distance and it will stop when we reach the intended place.

Imagine someone having a problem or damage in the muscle spindles, making his nervous system unable to know the rate of change of the length and therefore can't predict when he will reach the intended place, so if he wanted to reach a wall far from him 10m , he will not stop when he finishes those 10m instead he will stop when he hits the wall.

Let's study the difference between group 1a fibers (dynamic) and group 2 fibers (static)



Copyright © 2008, 2004, 1998, 1993, 1988, 1983 by Mosby, Inc., an affiliate of Elsevier Inc.

- ✓ Normally both types of receptors (nuclear bag and nuclear chain) have <u>basal rate offiring</u> and that's important because it makes positive and negative (inhibition) control possible. When the basal rate is 100 impulse/sec we can increase it to 200 impulse/sec or decrease it to 50 impulse/sec. If there is no basal rate (equals zero), we can't decrease the rate of firing.
- ✓ In the first case we have a dynamic change in it then it goes back to static :
    - During the dynamic change the rate of firing in group 1a fibers (dynamic) increases a lot [when rate of stretch increases, rate of firing increases], while in group 2 fibers (static) the rate of firing increases but to a lesser extent than in group 1a ➔ positive control
    - Now back to static stretch, group 1a fibers decrease their rate of firing returning to the basal rate, while with group 2 fibers firing rate stays almost the same.
- ✓ When there is a release of stretch (stretch decreases), the rate of firing in group 1a fibers will decrease a lot, while in group 2 fibers will decrease to lesser extent stayingalmost basal ➔ negative control
- ✓ How much increase or decrease in firing rate **depends on the rate of change**.

Something important to know before we proceed is that when the muscle is stretched, the muscle spindle will sense that stretch whether it was static or dynamic and those sensory neurons will go back to the spinal cord and to the brain telling it about this change (as we explained earlier), the same sensory neurons will synapse in the spinal cord with interneurons and those interneurons synapse with alpha motor neurons that supply the extrafusal muscle fibers contracting them that's because we don't want the muscle to stretch (increase in length) more than normal, contraction will shorten the muscle preserving it. Another explanation we took in anatomy, is that the muscle length in rest is shorter than its origin and insertion, which means that when the muscle is between its origin and insertion it is stretched – that stretch will stimulate muscle spindles which in turn will stimulate alpha motor neurons keeping the muscle contracting almost all the time maintaining its tone which helps us against the gravity.

Physiologic Function of the Muscle Spindle

1- Comparator of length between the intrafusal and extrafusal muscle fiber.
2- Opposes a change in length of the muscle.
3- When the muscle is stretched the spindle returns it to its original length.
4- Leads to the stretch reflex.

If the muscle spindle was de-innervated, we'd still be able to contract and relax the muscle [extrafusal fibers, but we wouldn't be able to *sustain* the contraction.

Smoothening effect of the Muscle Spindle

Now, let's get things together by talking about a phenomenon known as **alpha- gamma coactivation**

When the muscle is going to contract, alpha fibers must be stimulated. Sustained contraction will cause muscle spindle to become loose not sensing any change in stretch. Here comes the role of gamma fibers (which are **co-stimulated** with alpha fibers) causing contraction in the contractile parts ofthe muscle spindle stretching it (the same cycle is repeated | muscle spindle senses that stretch -> sends it back to the spinal cord -> activating alpha motor fibers allowing it to sustain the contraction)

Let's think about having those muscle spindles de-innervated (no gamma motor neurons are there) we will lose the stretch in the intrafusal fibers, no feedback stimulation for alpha motor fibers (inhibition), no sustained contraction, the contraction will lead to relaxation after it [the green graph].

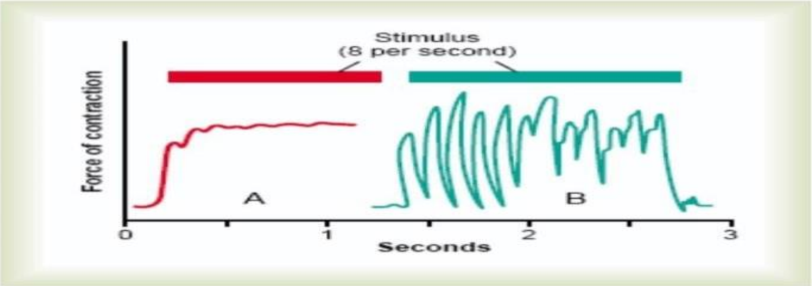


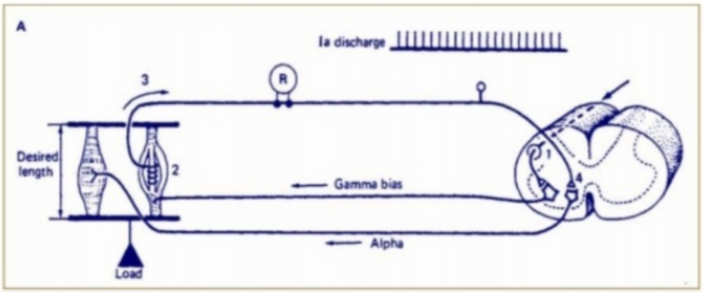
Figure 54–5

Muscle contraction caused by a spinal cord signal under two conditions: curve A, in a normal muscle, and curve B, in a muscle whose muscle spindles were denervated by section of the posterior roots of the cord 82 days previously. Note the smoothing effect of the muscle spindle reflex in curve A. (Modified from Creed RS, et al: Reflex Activity of the Spinal Cord. New York: Oxford University Press, 1932.)

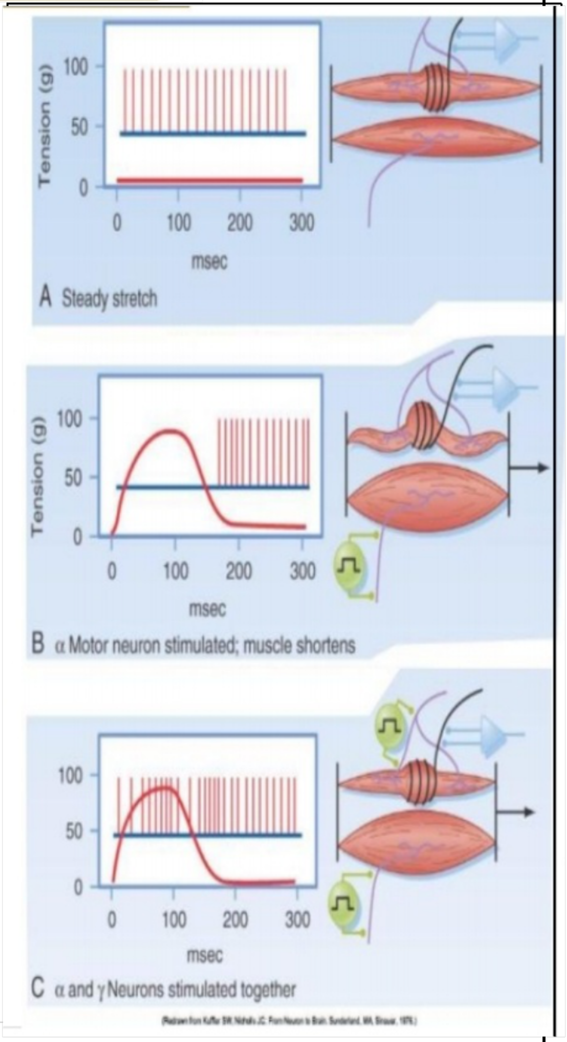
In this experiment, they attached a load to the muscle which will stretch the muscle and the muscle spindle in it, and they recorded the rate of firing in 1a sensory fibers.

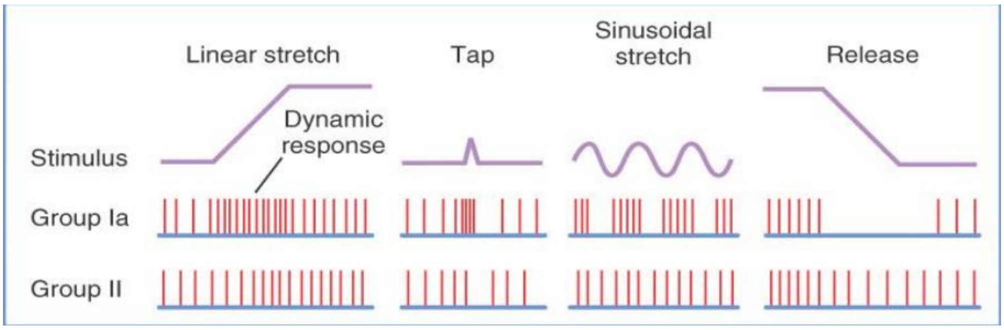
What happens?

1a fibers [sensory from the nuclear bag to the spinal cord] will sense the stretch and activate alpha motor fibers causing the muscle to contract and shorten. This will also shorten the muscle spindle and deactivate the stretch receptors. However, gamma motor fibers will be activated and they will contract the muscle spindle. Because of the unique arrangement of sarcomeres and nuclei in the muscle spindle, the peripheral parts will contract while the middle [which contains only nuclei] will stretch, reactivating the stretch receptors and sustaining the contraction of the muscle. <u>Alpha-gamma coactivation helps to maintain muscle contraction. Without this muscle spindle innervation through the coactivation, contraction can't be maintained.</u>



- In A we are recording a (static) stretch, there is basal firing in muscle spindle sensory fibers, without any change in the length of the muscle (isotonic).
- In B we are recording change in stretch (dynamic) but only alpha motor neurons are stimulated, that means we have contraction in the muscle, but notice there is no firing in the muscle spindle sensory fibers (why?) because muscle contraction will shorten muscle spindles loosening and inhibiting them, <u>without the presence of gamma fibers there will be no recording of any tension sensed by muscle spindle</u>.
- In C we are recording change in stretch (dynamic) with alpha and gamma neurons stimulated together (coactivated), muscle spindle will be contracted and activated all the time, when the muscle contracts there will be a decrease in the firing rate of muscle spindles. (<u>There is always a feedback to the CNS about the degree and change in stretch even in the case of contraction</u>)





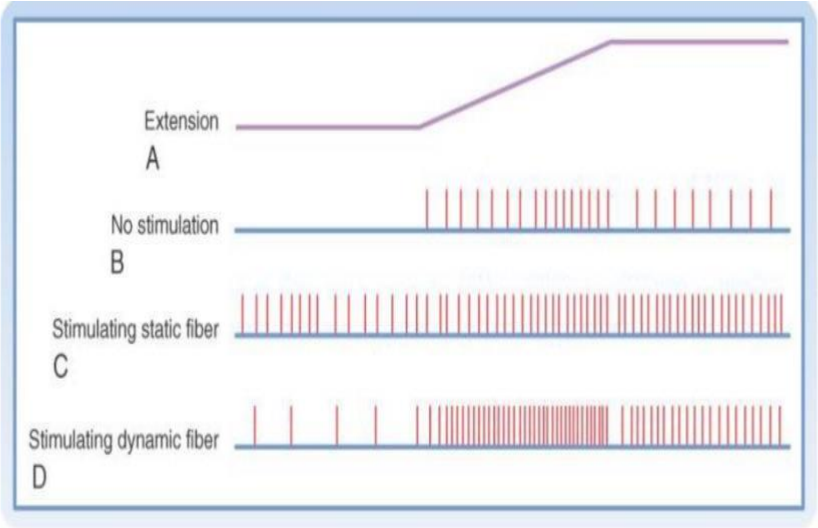
This figure shows the change in impulse rate in the dynamic sensory fibers [1a group]. During the stretch there's an increase in the firing rate then it goes back to normal [adapt]. When the load is released (the stretch is decreased), there's no firing. This happens in phasic receptors [on/off].

In the static fibers [group II], the rate of firing changes [increase and decrease] but it never reaches zero.

Function of the Gamma System:

1- Spindle is normally tonically active as a result of input from higher brain centers. Alpha-gamma co-activation helps maintain muscle contraction.
2- Controls the intensity of the stretch reflex.
3- Performs a damping function by adjusting sensitivity.

Effect of gamma motor fibers (Dynamic and static)



(Redrawn from Crowe A, Matthews PBC: J Physiol 174:109, 1964.)

When there is stretch change (dynamic), this will stimulate static gamma fibers increasing their impulse rate and stimulate dynamic gamma fibers increasing their impulse rate more. And when this change finishes, they will go back to their basal rate. Just like what happens with group 1a and 2 sensory fibers. But the increase and decrease of the firing rate in dynamic gamma fibers is more pronounced than in static gamma fibers.

Control of the Gamma Motor System (Fusimotor System)

- Gamma signal excited by the bulboreticular facilitatory area of the brain stem.
- Secondarily by areas that send impulses to this area. [cerebellum, basal ganglia, cortex]
- Little is known about the precise control of this system.

We will discuss reflexes Next. إن شاء الله!