PHYSIOLOGY

SHEET NO. 11

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Motor system – Motor of the spinal cord

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

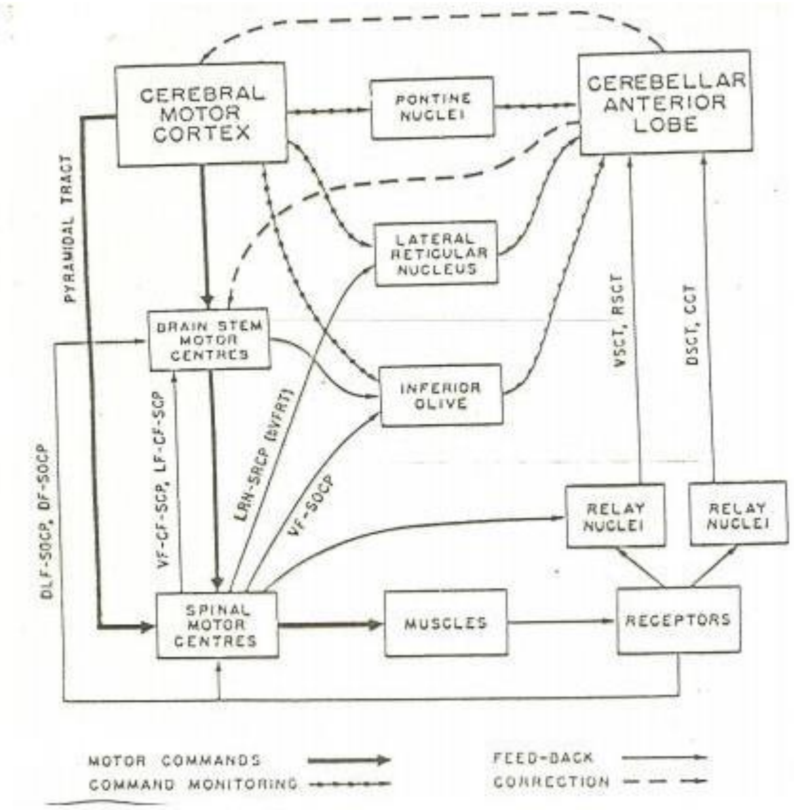
For any motor function (movement) to occur, the nervous system has motor command that comes **from the cerebral motor cortex to the spinal cord** and these descending tracts (**corticospinal**) are called also **pyramidal tracts** and that's because they pass through the pyramids of medulla oblongata.

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.

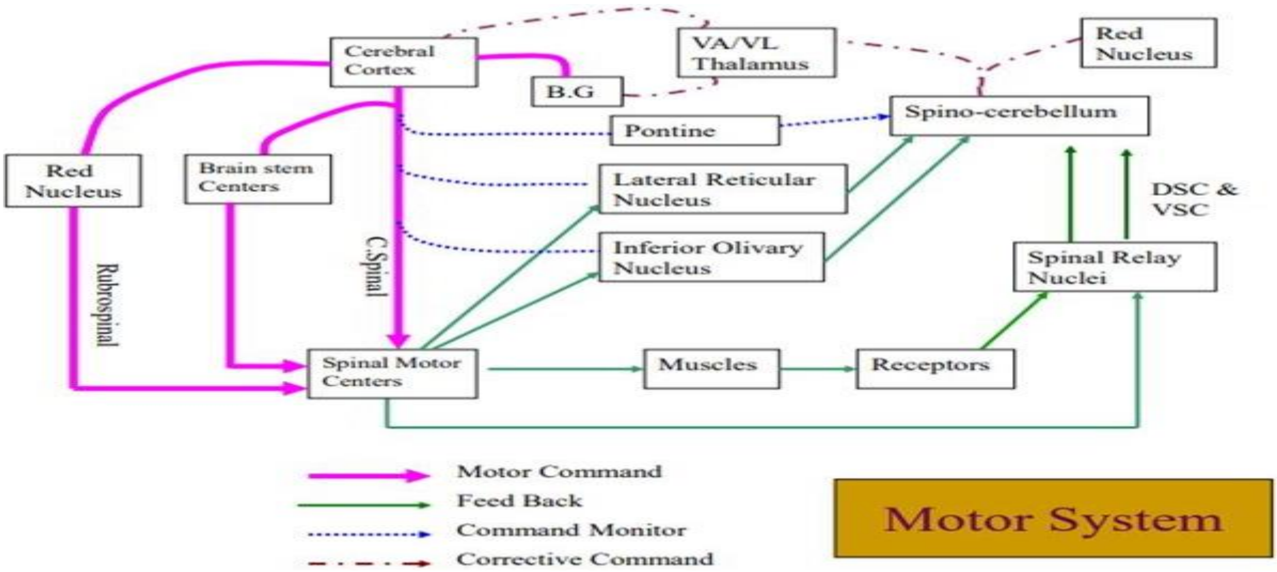
[receptors -> spinal cord -> ventral and dorsal spinocerebellar tracts -> cerebellum -> thalamus VA/VL -> cerebral cortex]

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.



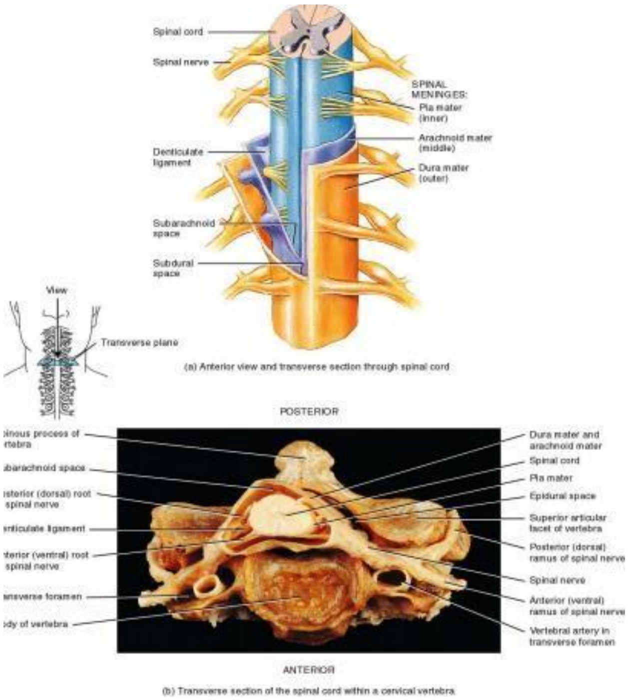
Why all of this is happening ? Usually the cerebral motor cortex doesn't send exact signals to the spinal cord (corticospinal tract), it sends either more or less than what is intended, so the muscles react more or less than what is intended. The cerebellum will know what is going on the level of the 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.*

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

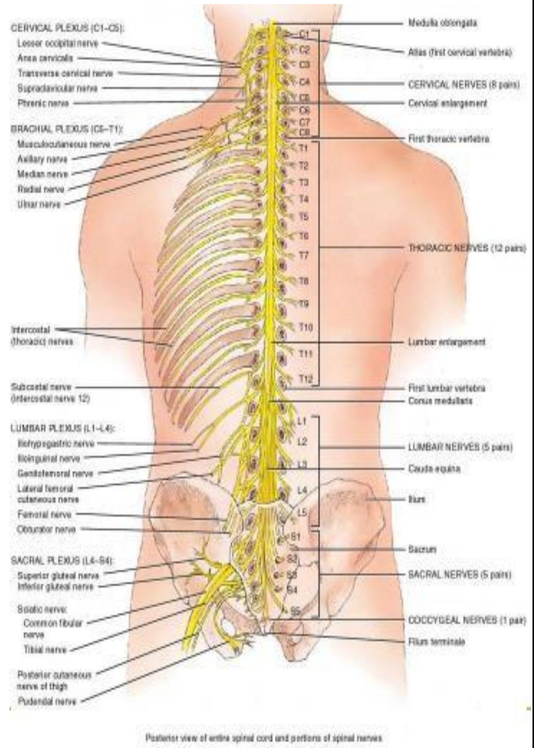
The spinal cord is the lowest part of this motor system, it is a pathway for the nerve fibers, Neuronal circuits for walking and various reflexes. And from the introduction we noticed that higher brain centers activate and command these circuits.



(a) Anterior view and transverse section through spinal cord
(b) Transverse section of the spinal cord within a cervical vertebra

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.

- 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 **cauda 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

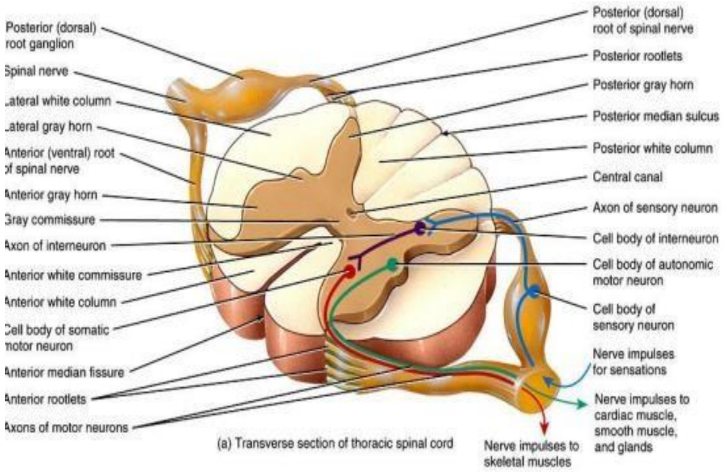


Figure 13.03 Tortora - PAP 12/e

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.

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.

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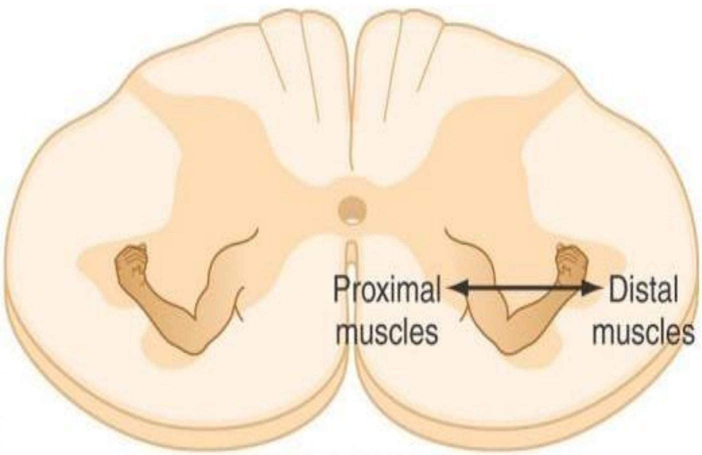
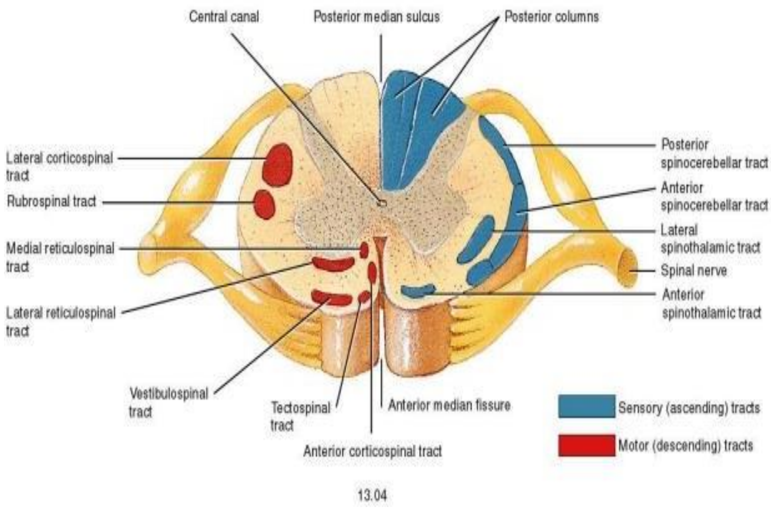


(Redrawn from Purves D et al (eds): Neuroscience, 3rd ed. Sunderland, MA, Sinauer, 2004.)

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:

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.

Sensory Receptors of the Muscle

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

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

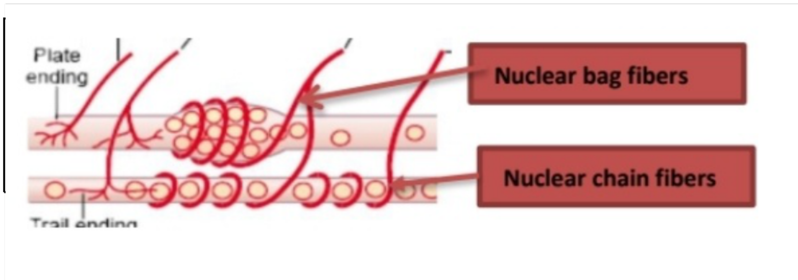
1- **Muscle Spindle**
   sense muscle length and change in length and rate of change in the length [***prediction***]
2- **Golgi Tendon Organ**
   sense tendon tension and the change in tension

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. <u>Muscles that are used most often like muscles working against the gravity (antigravity muscles) have a lot of muscle spindles and Golgi tendon organs.</u>

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]

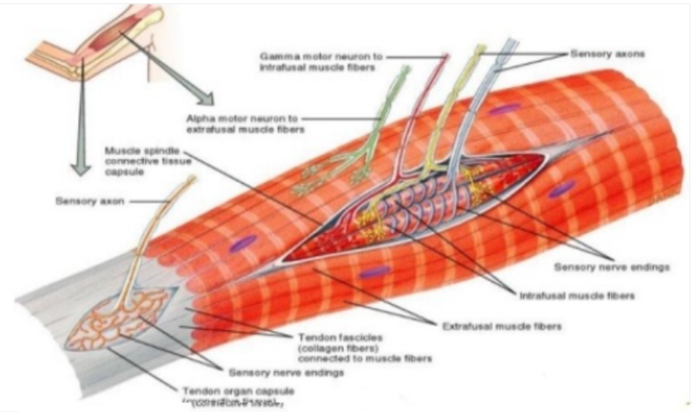
✓ There are two ways to activate a muscle spindle (stretch receptors):

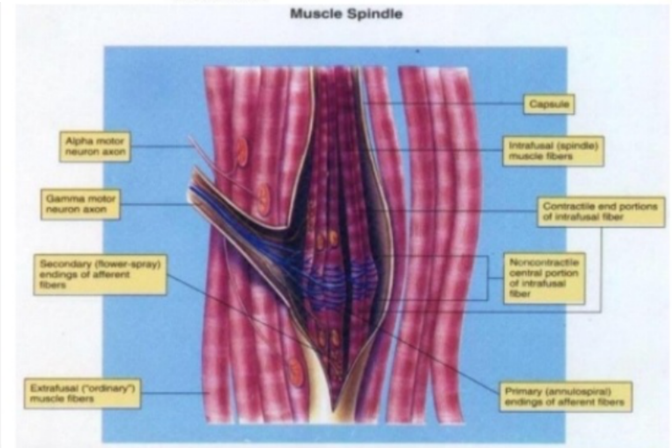
1- Any stretch in the muscle that lengthens it will stimulate the center of the muscle spindle.
2- Activation of gamma motor fibers will contract the contractile parts of the muscle spindle stimulating and keeping it stretched.

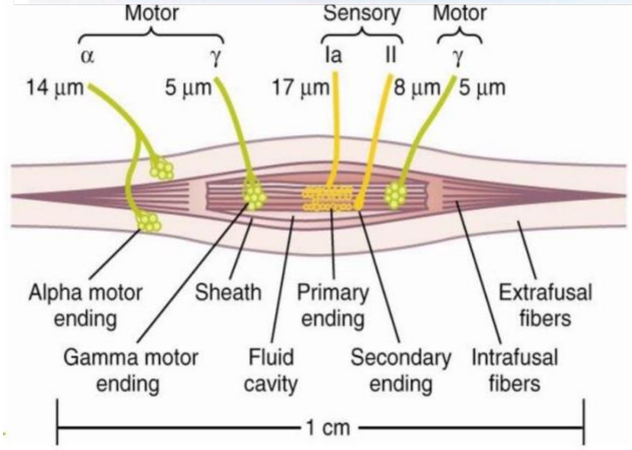
Static Response of the Muscle Spindle

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.







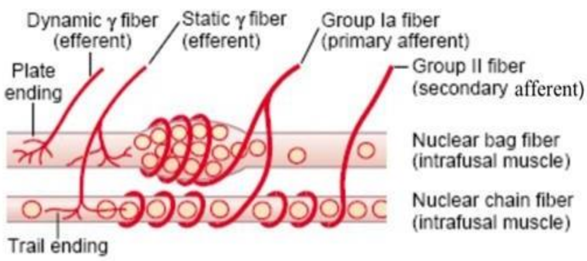


Figure 54–3

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.