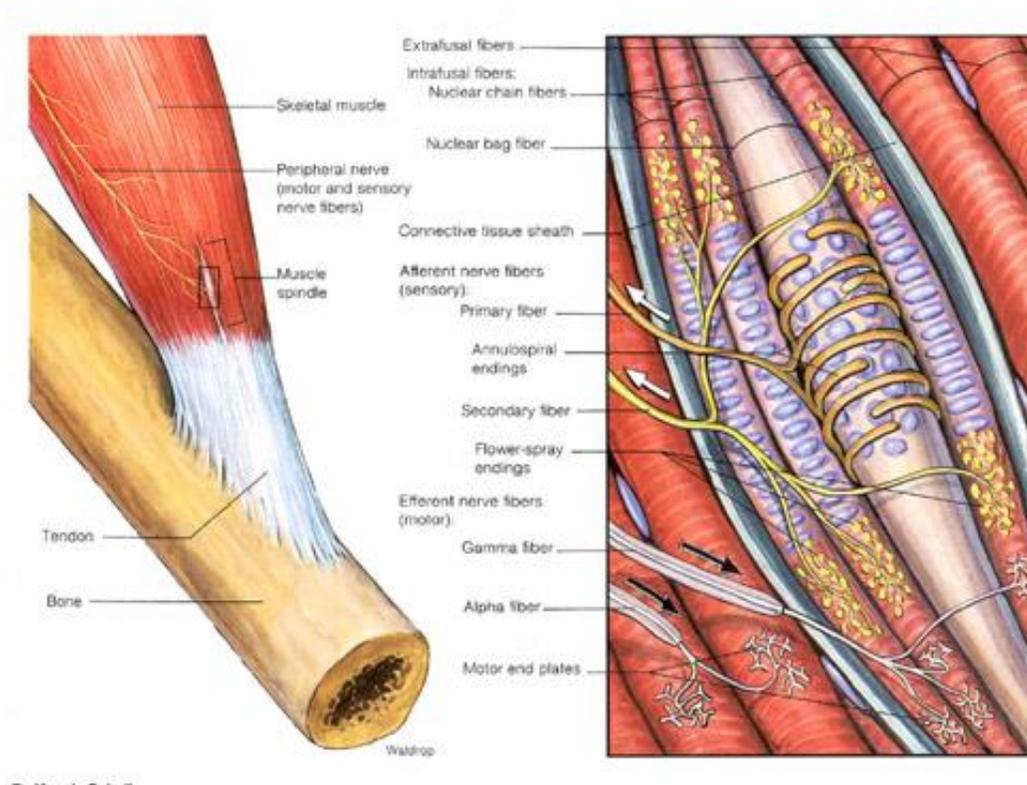


MUSCLE SPINDLE

INTRODUCTION:

The muscle spindle is a peripheral receptor located in the muscle belly of skeletal muscles. Each spindle consists of intrafusal fibers, sensory nerve endings, and gamma motor neuron endings. They are responsible for conveying information to the central nervous system about the absolute muscle length and changes in muscle length. Spindles play an important role in motor control and are used to help regulate muscle length during movement.

ANATOMY:



The **muscle spindle** is a **proprioceptor** located deep within the muscle parallel to the **extrafusal** muscle fibers. It is encapsulated in connective tissue and located directly inside the muscle interwoven between the **intrafusal** fibers. Each spindle is divided into three regions; equatorial (middle), juxta-equatorial, and polar ends (where the contractile mechanisms are located). The spindle consists of two types of intrafusal muscle fibers, nuclear bag and nuclear chain fibers. Each spindle contains 1-2 **nuclear bag fibers** and 5-7 **nuclear chain fibers**. The bag fibers have a clustering of nuclei in equatorial region of the spindle (resembling a bag), while the nuclei in the chain fibers are spread out. Due to the anatomy of these fibers, the bag fibers are much more compliant and less resistant to being stretched while the chain fibers are much stiffer.

The muscle spindle sends sensory information through both group Ia and group II afferent fibers. The 1a fibers (primary afferents) wrap around the chain and bag fibers in the equatorial region. The

primary afferents are thick (12-20 um in diameter) and heavily myelinated which allows for fast conduction (120 m/sec). These afferents increase their firing rate when there is a change in muscle length or rapid movement. They have a rapidly adapting response and therefore provide information about the velocity and direction of the muscle stretch. They also provide information about the rate of muscle length change and absolute muscle length. When returning to resting muscle length following a stretch these fibers tend to slack. The group II afferent fibers (secondary afferents) wrap about the chain and static bag fibers in the juxta-equatorial region. The secondary afferents are myelinated and slightly thinner than the primary afferents (6-12 um in diameters). These afferents produce a sustained response to constant muscle length and therefore provide information about the static muscle position. Following a stretch they passively return to resting muscle length and therefore are able to maintain tension and continue firing.

Spindles are innervated by efferent nerve fibers, **gamma-motor neurons**. The gamma motor neurons are located in the ventral horn with the **alpha motor neurons** and innervate the intrafusal fibers in the polar regions. There are two types of gamma motor neurons, dynamic and static. The dynamic neurons innervate the dynamic bag fibers while the static neurons innervate the static bag and chain fibers. The dynamic fibers increase the dynamic response in the Ia spindle receptors while the static fibers increase the static response of both Ia and II spindle afferents. The gamma-motor neurons are responsible for controlling the sensitivity of the spindle.

HOW IT WORKS:

There are three requirements in order for the muscle spindle to fire. First, there must be an adequate stimulation, meaning a change in muscle length and rate. Second, there must be intensity coding. The muscle spindle has a facilitator effect meaning it leads to excitation of the alpha motor neurons and contraction of the muscle. Finally, the firing of the muscle spindle depends on its sensory adaptations. The spindle consists of afferents that have mono-synaptic connections with alpha motor

neurons that are rapidly adapting.

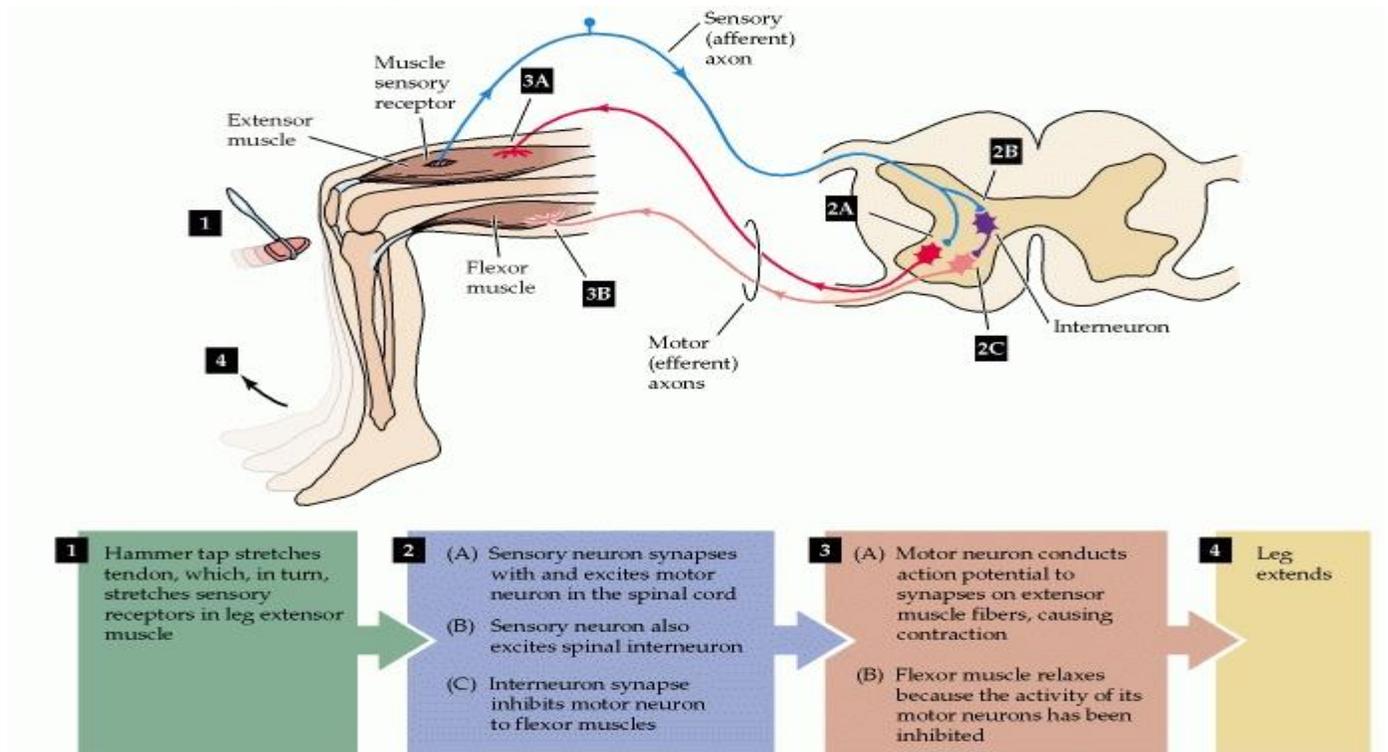
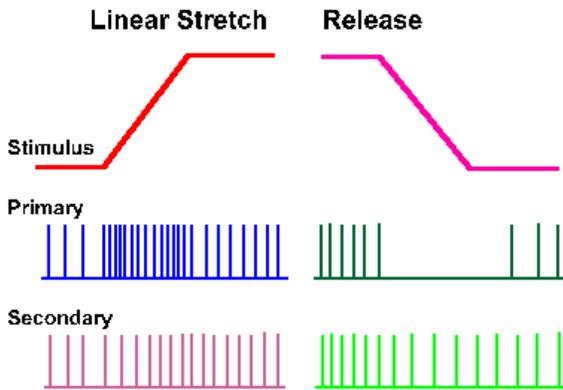


FIGURE : Above is a diagram explaining the myotatic stretch reflex.

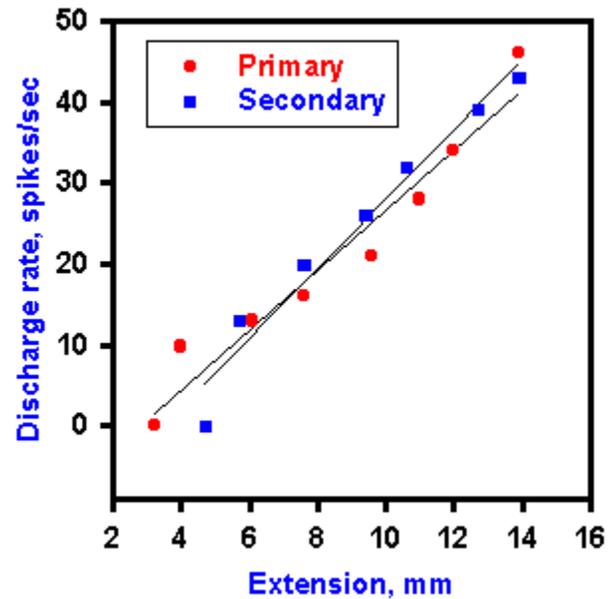
The muscle spindle works primarily through the **myotatic stretch reflex**. When a change in muscle length occurs the intrafusal fibers in the spindle are lengthened which pulls on the sensory nerve endings and causes mechanically gated ion channels in the spindle to open. This allows for an influx and a signal carrying information about the muscle length is propagated on a Ia or II afferent to the dorsal root of the spinal cord. Once the signal reaches the spinal cord it has a monosynaptic synapse with an alpha motor neuron that leads to the muscle where the spindle is located. This causes **autogenic excitation** and results in muscle contraction. There is also a synapse in the spinal cord with an inhibitory alpha motor neuron that goes to the antagonist muscle causing **reciprocal inhibition**. When the nervous system sends information to the alpha motor neurons it also sends information to the gamma motor neurons causing them to fire through **alpha-gamma coactivation**. Therefore as the muscle contracts gamma motor neurons are also firing in order to keep the spindle taut, which allows the spindle to function at all muscle lengths during movement and postural adjustments.



The rate at which the length changes is monitored by the Ia fibers around the dynamic bag fibers because these fibers are more compliant and less sensitive to stretch. These fibers are rapidly adapting so there is a quick change in their firing rate during muscle stretch but once the stretch is completed the Ia adapts and stops firing. The type II fibers which are attached to the chain intrafusal fibers monitor the static stretch and length of the muscle. These fibers are slowly adapting therefore they fire while the muscle is stretching and continue to fire after the muscle has stopped

moving. The difference in the firing of rates of the muscle spindle before and after a stretch or a change in length is called the **dynamic response**. If the difference is small this means there was a slow change in muscle length. However if the difference is large there was a rapid change in length. If the change in length is slow the firing rate of the Ia fibers tend to more closely resemble the firing rate of the static type II fibers. There is a linear relationship between the rate of discharge of the afferent fibers and the length of the muscle, meaning the static type II fibers will fire more tonically when the muscle is lengthened.

Although the muscle spindle is most responsive during active stretching it still plays during passive stretching. During passive stretching the spindle provides a resistance to slow muscle stretching. This is called **muscle tone**. The excitatory effect of the spindle during passive stretching is half the effect it normally has on Ia afferents. During active stretch only the Ia afferents are activated however, during passive stretching the polysynaptic type II endings are also activated.



CONTROL OF THE SPINDLE

The sensitivity of the muscle spindle is controlled through gamma efferent innervations. The gamma input keeps the spindle taut throughout the full range of motion allowing it to stay sensitive to stretch as the muscle contracts. The gamma static neurons decrease the dynamic response to Ia fibers during stretch because the resting static firing rate before the stretch begins is heightened. The gamma dynamic neurons increase the sensitivity to the rate of stretch for the Ia afferent but has almost no effect on the type II fibers.

The muscle spindle sensitivity can also be controlled by descending pathways. Descending neurons can change the tonic stretch of the reflex so that every time you stretch the spindle you get a

different strength of response. This is modulated by alpha-motor neurons usually at the pre-synaptic terminal of inhibitory afferent fibers at the renshaw cell. When a muscle contracts it also sends a collateral to a renshaw cell that stabilizes the firing rate so the limb does not continue to contract further after stretching. This regulates the motor neuron excitability and produces a recurrent inhibition of the motor neuron.

- use of pre-synaptic renshaw cells

- gamma motor neurons increase drive in order to increase sensitivity

- if you decrease gamma drive you decrease the affect on the alpha motor neurons

The response characteristics of the spindle afferents are chosen by the central nervous system according to the type of movement being performed. Static fibers are tend to be stimulated during predictable and stereotyped movements, such as stepping. During unpredictable movements, such as imposed movements, the majority of the fibers stimulated are dynamic. Research has been done showing that the muscle spindle responses similarly when performing the same movement, demonstrating the central nervous systems control of the muscle spindle. The study also examined the changes in a muscle spindle during a proprioceptive attention task. It found that the, "muscle spindle sensitivity to movement may be enhanced in completely relaxed subjects during the executive of a mental computation task showing that the central nervous system exerts a selective control of muscle spindle sensitivity via the fusimotor system (CHANGES).

PURPOSE OF THE SPINDLE:

The muscle spindle plays an important role in motor control. It helps to maintain a constant muscle length. It is also a source of muscle tone as it provides a resistance to stretch and is involved in the stretch reflex. The stretch reflex allows for protection from painful or damaging stimuli. The static component of the spindles is involved in maintaining upright posture. The spindle is the highest density in muscles that initiate fine movement or are used to maintain posture (ie. Hand, foot, neck). The spindle also plays a subtle role in smoothing voluntary movements and allowing for movement coordination.

DYSFUNCTION IN THE MUSCLE SPINDLE

There can be a loss of supraspinal inhibition due to a upper motor neuron lesion. A basal ganglia disorder can cause excessive supraspinal activation. Problems with the muscles spindle can lead to abnormal muscle tone such as spasticity (a velocity dependent increase in resistance to passive stretch which causes exaggerated tendon reflexes called hyper reflexia). There are several causes of spasticity associated with the muscle spindle. First, overactive gamma motor neuron input or increased excitability at the central synapse will lead to spasticity. This usually occurs due cortical damage and a loss of inhibitory impulses. Second, spasticity can be caused by problems with the renshaw cells. Problems with the renshaw cells leads to a loss of inhibition on the alpha motor neurons so they simply continue firing. Third, spasticity can arise from a pre-synaptic inhibition of Ia afferent. Finally, it can arise from a neuro-related or structural change in the muscle fibers.

GLOSSARY

Mechanoreceptors: receptors specialized to sense mechanical forces

Intrafusal muscle fibers: specialized muscle fibers found in muscle spindle

Alpha motor neuron: neurons in the ventral horn of the spinal cord that innervate skeletal muscle

Gamma motor neuron: class of spinal motor neurons specially concerned with the regulation of muscle spindle length; these neurons innervate the intrafusal muscle fibers of the spindle; two types, static and dynamic

Myotatic reflex: a fundamental spinal reflex that is generated by the motor response to afferent sensory information arising from muscle spindles. The “knee jerk reaction” is a common example. Also called a stretch reflex.

Extrafusal muscle fiber: fibers of the skeletal muscles; a term that distinguishes ordinary muscle fibers from the specialized intrafusal fibers associated with muscle spindle

Muscle spindle: highly specialized sensory organ found in most skeletal muscles; provides mechanosensory information about muscle length

Muscle tone: the normal, ongoing tension in a muscle; measured by resistance of a muscle to passive stretching

Proprioceptors: sensory receptors (usually limited to mechanosensory receptors) that sense the internal forces acting on the body; muscle spindles and Golgi tendon organs are the preeminent examples

Nuclear bag fibers: consists of both static and dynamic fibers; has spherical nuclei in its central noncontractile region and has less resistance to stretch

Nuclear chain fibers: consists of static fibers; has a single row of nuclei and is more resistant to stretch

Autogenic excitation: afferent signals synapses in the spinal cord to produce a strong excitatory drive to the muscle from which the signal originates

Reciprocal inhibition: reflex inhibition of a motor unit in response to excessive tension in the muscle fiber it supplies

Alpha-gamma coactivation: prevent the silencing of the muscle spindle during shortening such that changes in sensitivity correlate with changes in muscular activity

Dynamic response: code sensory information about the rate of stretch

Static response: code muscle length and limb position