Neuromuscular Control of the Skeleton

THESIS

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بسم الله الرحمن الرحيم

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Introduction:

Somatic motor activity depends ultimately upon the pattern and rate of discharge of the spinal motor neurons. These neurons -the final common paths to skeletal muscles- are bombarded by impulses from an immense array of pathways.

There are many inputs to each spinal motor neuron, from the same spinal segment. Numerous suprasegmental inputs also converge on these cells, in part via interneurons and in part via the neurons of the gamma (γ) efferent system to the muscle spindles and back through afferent fibres to the spinal cord.

It is the integrated activity of these multible inputs from spinal, brain stem and cortical levels that regulate the posture of the body and make coordinated movements possible.

In the following chapter we will discuss the motor functions of the different parts of the C.N.S., including : the spinal cord, brain stem, basal ganglia, cerebellum and cerebral cortex. Finally we will discuss the motor function of the C.N.S. as a whole as divided into pyramidal and extrapyrapyramidal sydtems.

I Motor Functions of the Spinal Cord

Anatomical Considerations:

Each segment of the spinal cord has several million neurons in its gray matter. Aside from sensory neurones that relay impulses to the brain, these neurons are divided into two types: (1) the anterior motoneurons and , (2) the interneurons.

(1) Anterior Motoneurons :

The anterior motoneurons are located in the anterior horns of the cord gray matter. They are 50 to 100 % larger than most of the other neurons. They give rise to nerve fibres that leave the cord via the anterior roots and innervate skeletal muscle fibres . These neurons are of two types:

(a) Alpha (α) Motoneurons :

The α motoneurons give rise to large type A_{α} nerve fbres that innervate the ordinary skeletal fibres.

(b) Gamma (γ) Motoneurons :

The γ motoneurons are about half or much smaller than the α motoneurons. They transmit impulses through type A_{γ} nerve fibres to special skeletal muscle fibers called the intrafusal muscle fibres .

These fibres are part of the muscle spindles .

(2) Interneurons :

The interneurons are present in all areas of the cord gray matter, in the anterior horns, posterior horns and the intermediate area between them. They are about 30 times as numerous as the anterior motoneurons. They are small and highly excitable. They have many interconnections one with the other and with anterior motoneurons .

Most of sensory signals to the cord through posterior roots, and descending signals from the brain, are transmitted first to interneurons where they are appropriately processed before stimulting the anterior motoneurons.

More than half of all fibres ascending and descending in the cord are propriospinal fibres that run from one segment of the cord to another. In addition , the terminal sensory fibres,as they enter the cord, branch both upward and downward. These ascending and descending fibres of the cord provide pathways for the multisegmental reflexes that coordinate movemnts in both upper and lower limbs simultaneously.(Guyton 1981)

-Spinal Cord Reflexes :

Introduction:

The basic unit of integerated neural activity is the reflex arc. This arc consists of a sense organ, an afferent neuron, one or more synapses in a central integrating station, an efferent neuron and an affector. The simplest reflex arc is one with a single synapse between the afferent and efferent neurons. Such arcs are monosynaptic. Reflex arcs in which one or more interneurons are interposed between the afferent and efferen neurons are polysynaptic. The number of synapses in polysynaptic reflexes varies from 2 to many hundreds. (Ganong 1983).

Postural reflexes are series of reflexes that maintain the body in an upright balanced position and provide constant adjustments necessary to maintain a stable postural background for voluntary activity. These adjustments include maintained static reflexes and short term dynamic reflexes. Static reflexes involve sustained contraction of the musculature, while dynamic reflexes involve transient movements .

Postural reflexes are integerated at various levels in the C.N.S. from the spinal cord to the cerebral cortex and are affected through extrapyramidal motor pathways.

In intact animals the individual motor responses are fitted into the total pattern of motor activity. When the neural axis is transected, the activities integerated below the section are released from the control of higher centres and appear to be accentuated. This apparent hyperactivity may be due to removal of an inhibitory control by higher centres or more importantly due to loss of differentiation of the reaction, so that it no longer fits in the broader pattern of motor activity. (Ganong 1983).

The postural reflexes that are integerated in the spinal cord include the stretch reflexes, the golgi tendon reflex and nociceptive flexion reflexes.

I Stretch Reflexes :

The sensory organ for stretch reflexes is the muscle spindle. The complexity of structure of the muscle spindle allows it to inetiate different types of stretch reflexes .

Structure of the Muscle Spindle :

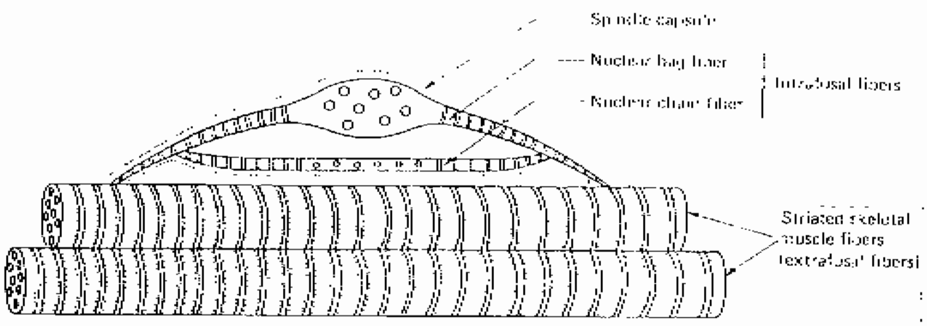

Figure 1.1 : Schematic Illustration of a Muscle Spindle

Each muscle spindle contains 2 specialized types of muscle fibers enclosed in a connective tissue capsule.These fibres are called the interfusal muscle fibres to distinguish them from the extrafusal fibres, the regular contractile units of the muscle. Intrafusal fibres are more embryonal in character and have less distinct striations. (Ganong 1983)

They are in parallel with the rest of muscle fibres because the ends of the spindle capsule are attached to the sides of the extrafusal fibres . (Kottke 1982)

The two types of intrafusal muscle fibres are :

(1) Nuclear Bag Intrafusal Muscle Fibres :

The nuclear bag intrafusal muscle fibers have all their neuclei collected at the equatorial region of the fibre. Myofibrils run through the 2 polar ends . Consequently, the nuclear bag is stretched when the myofibrils of that cell contract. There may be from one to six nuclear bag fibres in each spindle . (Kottke 1982)

(2) Nuclear Chain Intrafusal Muscle Fibres :

The nuclear chain fibres are much smaller than the nuclear bag fibres. Their number per spindle varies from one to ten.The raw of nuclei scattered along the central portion of the fiber gives the nuclear chain fibre its name. There are myofibrils concentrated in the polar regions but also running through the central region where the nuclei are located. The arrangement of myofibrils in the nuclear chain fibres have not been demonstrated, but it appears that contraction of nuclear chain fibres stretches and discharges the sensory endings surrounding them. (Kottke 1982)

Innervation of the Muscle Spindle :

(a) Motor Innervation :

The intrafusal muscle fibres receive their motor innervation from the small gamma (γ) efferent nerve fibres which are axons of γ motor neurons. There are 2 types of efferent nerve fibres : (1) dynamic γ efferents and (2) static γ efferents. Dynamic γ efferents end with motor end plates or plate endings on nuclear bag fibres. Static γ efferents form extensive networks or trail endings on nuclear chain fibers.,(Canong 1983)

(b) Sensory Innervation :

The muscle spindle is innervated by 2 types of sensory fibres: (1) the group I a or primary sensory fibres and(2) the group II or secondary sensory fibres .

The primary sensory fibres have annulospiral endings that wrap around the centre of the intrafusal muscle fibres.

The secondary sensory fibres have flower spray endings which are located near the ends of the intrafusal fibres. (Ganong W.F.)

The flower spray endings are so called because in some preparations they look like flower sprays, even though they mainly encircle the intrafusal fibres in the same way that primary fibres do . (Guyton 1981)

There is only one primary sensory fibre per muscle spindle, this fibre branches to innervate multiple nuclear bag and nuclear chain fibres . (Mathews 1972)

The two types of intrafusal fibres, each with 2 types of sensory innervation and a special type of motor innervation, provide the muscle spindle with possibility for complex responses in excitation of reflex activity .

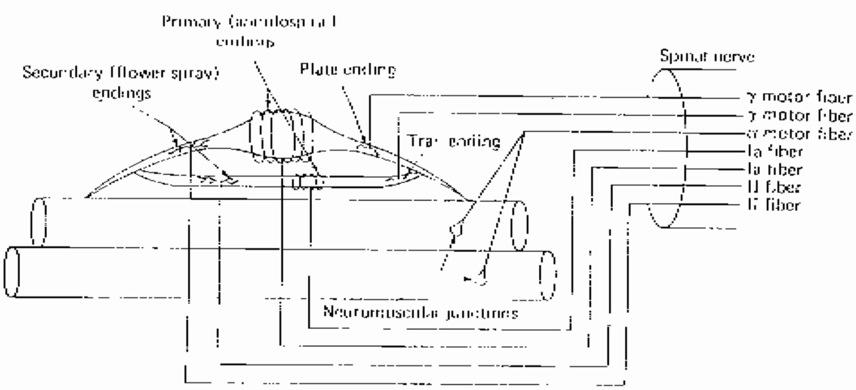

Figure 1.2 :Schematic Illustration showing the Innervation of a Muscle Spindle

Central Connections of Afferent Fibres from Muscle Spindle:

The fibres from the primary endings end directly on motor neurons nervating the extrafusal fibres of the same muscle.

The fibres from the secondary endings make connections that cause muscle contraction through polysynaptic reflexes.(Ganong 1983)

Collaterals from spindle afferents synapse on neurons of the spinocerebellar tracts . The second order neurons of these tracts conduct information concerning the state of muscle tone and movement to the cerebellum. (Stratton 1981)

Primary Stretch Reflex :

The primary stretch reflex can be subdivided into the dynamic response that arises from stretching the primary endings on nuclear bag fibres, and the static response arising from stretching of the primary endings on the nuclear chain fibers .

Dynamic Primary Stretch Reflex :

Stretch of primary endings on nuclear bag fibres produce a burst of impulses that accomodate rapidly . (Mathews 1972)

When a muscle is suddenly stretched, a potent dynamic signal is transmitted via the primary sensory fibers to the spinal cord, and this causes an instantaneous very strong contraction of the same muscle from which the signal originated . This dynamic stretch reflex is over within a fraction of a second after the muscle have been stretched to its new length. The dynamic reflex opposes sudden changes in muscle length . (Guyton 1981)

Static Primary Stretch Reflex :

The primary endings on nuclear chain fibres have higher threshold so that they do not begin to discharge until a certain degree of stretch has been exceeded , and then they continue to discharge for the duration of stretch at a rate that increases slowly with any further increase in stretch . (Mathews 1972) .

The continuous static signalstransmitted via the primary fibres on the nuclear chain fibres, cause a static reflex that produces a much weaker muscle contraction, as long as the muscle is maintained at an excessive length,for as long as several hours. The contraction in turn opposes the force that is causing the excess length. (Guyton 1981)

Effect of γ -efferent Stimulation on Sensitivity of Stretch Reflexes:

The sensory endings on intrafusal muscle fibres will be stretched if the entire muscle is stretched . They will also be stretched if the intrefusal muscle fibres contract in response to γ-efferent stimulation .

If the whole muscle is stretched during γ-efferent stimulation additional stretch on the sensory endings occurs . Therefore dynamic γ - efferent stimulation increases the sensitivity of sensory endings on nuclear bag fibres and static γ -efferent stimulation enhances the sensitivity of the sensory endings on the nuclear chain fibres . (Mathews 1972)

Functions of Primary Stretch Reflex:

1) Feed-back Control of Muscle Length :

When a muscle is lengthened both dynamic and static primary stretch reflexes cause muscle contraction that tends to bring the muscle to its original length. When a muscle is suddenly shortened, exact opposite effects occur. If the muscle is already taut, any sudden release of the load on the muscle that allows it to shorten, will elicit both dynamic and static reflex inhibition rather than reflex excitation . This inverse or negative stretch reflex opposes shortening of the muscle in the same way that the positive stretch reflex oppposes lengthening of the muscle . Therefore, the primary stretch reflex constitutes a feed-back device that operates to maintain muscle length.(Cuyton1981)

2) Damping Function :

Another extremely important function of the stretch reflex is its ability to prevent some types of oscilations or jerkiness of body movements. This a damping or smoothing function. (Guyton1981)

3) Role of Primary Stretch Reflex in Voluntary Motor Activity:

Whenever signals are transmitted to α motoneurons almost invariably γ motoneurons are stimulated simultaneously, an effect called coactivation of α and γ motoneurons or α and γ linkage . (Guyton 1981). This linkage causes contraction of the intrafusal muscle fibres equal to or exceeding the contraction of the extrafusal motor units .(Mathews 1972)

This co-contraction keeps the muscle spindle from opposing voluntary muscle contraction by the inverse stretch reflex, (Guyton 1981). It also maintains the spindle capable of responding to stretch , and reflexly adjusting motor neuron discharge throughout the contraction . (Ganong 1983) .