2. MUSCLE RECEPTORS AND SPINAL REFLEXES

NERVE NOMENCLATURE
The overall criteria to differentiate the type of nerve fibers are the diameter and structure of the fibers which in turn are correlated with the velocity with which they are capable of conducting an action potential. Nerve fibers are also named or classified according to their function (sensory or motor) or under a general classification. In particular, when classifying nerves with a sensory function, these are assigned a Roman number I, II, III, or IV. I being the larger diameter and fastest fibers while IV the smaller and slowest fibers. If the nerves are classified within the “general” nomenclature they are named with Arabic letters (A or C), which also separates them into myelinated and unmyelinated, respectively. Those fibers in the “A” classification are further divided in subclasses identified with Greek letters (α, β, γ, δ). Alpha fibers are larger and faster while δ fibers are smaller and slower (Fig. 2-1).

### TYPES OF NERVE FIBERS, THEIR CHARACTERISTICS AND FUNCTION

<table>
<thead>
<tr>
<th>Name Type</th>
<th>Diameter (µm)</th>
<th>Velocity (m/sec)</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aα or IA</td>
<td>12-20</td>
<td>70-120</td>
<td>Motor efferent to extrafusal muscle, afferent from muscle spindle proprioceptive endings</td>
</tr>
<tr>
<td>Aβ or IB</td>
<td>10-15</td>
<td>60-80</td>
<td>Afferent (sensory) information from tendons and Ruffini receptors in the skin</td>
</tr>
<tr>
<td>II</td>
<td>5-15</td>
<td>30-80</td>
<td>Afferent (sensory) proprioceptive from muscle spindles, and form Meissner’s and Pacinian corpuscles.</td>
</tr>
<tr>
<td>Ay</td>
<td>3-8</td>
<td>15-40</td>
<td>Efferent (motor) to intrafusal fibres of muscle spindles</td>
</tr>
<tr>
<td>Aδ or III</td>
<td>3-8</td>
<td>10-30</td>
<td>Afferent from hair follicles, free nerve endings (temperature and pain)</td>
</tr>
<tr>
<td>C or IV</td>
<td>0.5-2</td>
<td>0.5-2</td>
<td>Afferent for pain, temperature, touch and pressure. Efferent for postganglionic autonomic (sympathetic)</td>
</tr>
</tbody>
</table>

Figure 2-1. Characteristics and function of the different types of nerve fibres
Reflexes

Within a muscle there are several types of muscle fibres. We are specifically interested in the differentiation between intrafusal and extrafusal muscle fibres (Fig. 2-2). Extrafusal fibres are those innervated by Aα motor neurons and are in charge of causing muscle contraction. Intrafusal muscle fibres are specialized structures that make up the muscle spindles that are innervated by Aγ motor neurons. The spindles have a fusiform form where the name “intrafusal” is derived. These fibres, which in themselves are proprioceptors, are located within the muscle but are isolated by a collagen sheath. As a proprioceptor their role is to detect the amount and the rate with which a muscle length changes. Each spindle has two contractile sections at the poles which are innervated by Aγ motor neurons and a non contractile section in the middle which is innervated by afferent sensory fibers Ia and II. The Ia sensory fibre tracks the rate or how fast the muscle is stretching. The Type II sensory fibers detect the amount of stretching taking place. Type II fibers are non-adaptive thus they keep sending action potentials with this information after the muscle has finished stretching.

The simplest functional unit of the nervous system is the reflex arc. The action of the reflex arc is to perform an automatic response, without conscious thought. A reflex consists in sensing a stimulus, and generating an appropriate response.

The basic components of the reflex arc are the following: a receptor, a sensory neuron, an interneuron, a motor neuron and the effector organ (Fig. 2-3). The sensory receptor detects the stimulus and converts the information into an action potential that is conveyed by the sensory neuron. The body of the sensory neurone is located in the dorsal root ganglion; its axon goes to the dorsal horn of the
spinal cord where it synapses with an interneuron. This interneuron in turn synapses in the anterior or ventral horn of the spinal cord with a motor neuron. The action potential is then carried by the motor neuron, which exits the spinal cord through the ventral root of the spinal nerve, and synapses with the effector organ (muscle or gland) that carries out the response. There are even simpler reflexes, which are called monosynaptic reflexes which do not have an interneuron. The sensory neuron directly synapses with the efferent motor neuron. All reflexes that involve a small segment of the CNS are classified as segmental reflexes (Fig. 2-4). Some reflexes also include more connections than those described above and involve integration in the spinal cord or the brain. These are classified as intersegmental reflexes. Most reflexes activated by proprioception are under this classification because the afferent information may reach as high as the cerebral cortex where the motor response is integrated. Reflexes can also have, as a part of the response, activation of an excitatory neuron (contraction of a muscle) and, at the same time, an inhibitory neuron (relaxation of the opposite muscle).

The major reflexes integrated at the level of the spinal cord are the stretch reflex, the withdrawal reflex and the Golgi tendon reflex (Fig. 2-5).

**Stretch Reflex**
The stretch reflex is one of the simplest reflexes which contract a muscle that is being stretched. The stretch reflex is mediated through a monosynaptic arc and it contributes to the maintenance of steady standing posture and to coordinate muscle movement. In this reflex the sensory receptor consists of several (3-10) specialized skeletal muscle fibres which make a muscle spindle.

The skeletal muscle fibers of the spindle are innervated by Ay motor neurons derived from the spinal cord. Sensory neurons innervate the center of the muscle spindle and carry information to the spinal cord, where they synapse with Aα motor neurons which then innervate the muscle in which the spindle is located (Fig. 2-2). When the muscle stretches the spindle detects this pattern through the sensory neuron which carries the action potential to the spinal cord, where it synapses with the Aα motor neuron. The Aα motor neuron then carries the action potential to the muscle in which the spindle is located and triggers its contraction to resist being stretched. The role of the Ay motor neuron is to regulate the sensitivity of the muscle spindle as the muscle shortens. They regulate the sensitivity by

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### COMMON REFLEXES

- **Stretch or myotactic reflex** (Monosynaptic, polysynaptic)
  - Prevent overstretching of muscle
- **Golgi tendon reflex** (Polysynaptic)
  - Prevent damage to tendons
- **Withdrawal or flexor reflex** (Polysynaptic)
  - Remove appendix or area from noxious stimulus

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### STRETCH REFLEX

**Muscle spindle**

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**Figure 2-5. Characteristics and role of the most common reflexes**

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**Figure 2-6. Components of a muscle spindle**
shortening the muscles of the spindle, thus matching the tension with the muscle (Fig. 2-6).

**Golgi tendon reflex**
The Golgi tendon reflex, a polysynaptic arc, prevents a contracting muscle from causing damage to the tendon which supports it. This system responds only to intense stretching of the tendon. The Golgi tendon organ, acts as a sensory receptor which is located within the tendon close to the junction between the tendon and the muscle. When the muscle shortens, it causes stretching of the tendon which, if severe enough, will cause an action potential in the sensory neuron. This action potential will be carried to the spinal cord where it will connect to the brain and also to an inhibitory interneuron which in turn will synapse with the Aα motor neuron inhibiting its function. This will cause the relaxation of the initially contracting muscle, thus reducing the tension on the tendon.

**Withdrawal or flexor reflex**
This reflex is a protective response to a noxious stimulus since it removes an area of the body away from a painful stimulus. The painful stimulus triggers an action potential which is conducted by a sensory neuron to the spinal cord where it synapses with several stimulatory interneurons. These interneurons in turn synapse with Aα motor neurons which connect and stimulate the muscles which are in charge of moving the limb or the part of the body away from the painful stimulus. If the animal needs to flex a limb to avoid a painful stimulus, then, in order to make the reflex more efficient, it is common that collateral axons of the sensory neuron will synapse with inhibitory interneurons in the spinal cord which in turn synapses with Aα motor neurons connected to the extensor muscle for the limb to be moved. These connections are called reciprocal innervations. Also associated with the withdrawal reflex is the crossed extensor reflex. In this reflex the interneurons in charge of stimulating the Aα motor neurons which stimulate the withdrawal of the limb, have collateral axons that cross the spinal cord and stimulate the extensor muscles in the opposite side of the animal. This action permits switching the load to the unaffected limb to prevent a potential fall.

**Posture and locomotion**
The movements that an animal performs can be separated into two large categories (Fig. 2-7). One category includes all those movements done in a voluntary manner. The animal is conscious of them and many of the movements are learned and perfected through practice. Most of these involve flexor muscles. All of these contribute to locomotion and other movements such as food ingestion.

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**POSTURE AND LOCOMOTION**

<table>
<thead>
<tr>
<th>Voluntary movements</th>
<th>Involuntary movements</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Animal is aware</td>
<td>- Maintains posture and equilibrium</td>
</tr>
<tr>
<td>- Perfected through practice</td>
<td>- Animal is not aware</td>
</tr>
<tr>
<td>- Involves flexor muscles</td>
<td>- Involves extensor or antigravity muscles</td>
</tr>
<tr>
<td>- Triggered by neurons in pyramidal system</td>
<td>- Triggered by neurons in extrapyramidal system</td>
</tr>
<tr>
<td>- Corticospinal tract</td>
<td>- Both fine-tuned by cerebellum</td>
</tr>
<tr>
<td>- From cerebral cortex (crosses)</td>
<td></td>
</tr>
<tr>
<td>- Corticobulbar</td>
<td></td>
</tr>
<tr>
<td>- From brainstem</td>
<td></td>
</tr>
</tbody>
</table>

Figure 2-7. Differences in the generation and role of voluntary and involuntary movements
Voluntary movements are triggered by a group of upper motor neurons which make up the **pyramidal system**. This name is derived from the shape of this bundle of neurons, which originate in the cerebral cortex as they pass through the medulla oblongata. Two nerve tracts are identified within the pyramidal system. The **corticospinal** tract starts in the cerebral cortex and descends to the contra lateral side of the spinal cord to synapse with lower motor neurons. About 90% of the fibres cross within the medulla oblongata. The rest descend ipsilaterally through the spinal cord and they eventually cross at different segments of the spinal cord to synapse with lower motor neurons. The second pyramidal nervous tract is the **corticobulbar** tract which follows a similar path to the corticospinal tract but finishes in the brainstem. From here they synapse with lower motor neurons connected to muscles in the head.

The second category of muscle contraction includes all involuntary activity dedicated to maintaining posture and equilibrium (Fig. 2-7). These require the participation and contraction of extensor muscles commonly called antigravity muscles because they maintain the animal in standing position, thus defying gravity. The motor activation for all of these muscles is mainly done subconsciously, in an involuntary manner by a group of upper motor neurons which constitute the **extrapyramidal system**. To maintain standing position there is a continual contraction of groups of muscles. In conjunction with the two systems of upper motor neurons, the cerebellum fine-tunes and corrects the movements initiated by the above-mentioned upper motor neurons. Details of the cerebellum involvement will be discussed in a later section.

**Differentiation between upper and lower motor neuron disease**

All animals with neurologic disease exhibit typical signs related to abnormal posture or locomotion. A neurological exam is essential to differentiate between damage to the upper or lower motor neurons. If the upper motor neurons are involved then the damage is done to neurons of the CNS. Damage to these neurons causes typical clinical signs (Fig. 2-8), all characterized by inappropriate movement. These range from seizures, rigidity, circling patterns and others; if the damage is to the brain. If the spinal cord is damaged, typically some degree of weakness to the portion caudal to the damage is observed. Usually when the problem is with upper motor neurons, the muscles of the limbs affected do not undergo atrophy. Animals with upper motor neuron disease retain the capability of performing most segmental reflexes.

**UPPER MOTOR NEURON DISEASE**

- Inappropriate movements
  - Brain (seizures, rigidity, circling patterns, unknown limb position)
- No atrophy
  - Muscle mass of affected area is retained
- Segmental reflex are present
  - Component of reflex are intact

*Figure 2-8. Clinical signs of upper motor neuron disease*

If lower motor neuron disease is identified then the damage is to the axons of Aα neurons or the neuron–muscular junction is compromised. These neurons have their body and dendrites within the CNS, however their axon projects through the ventral root and synapses with extrafusal skeletal muscle fibres. If the action potential cannot be delivered to the extrafusal skeletal muscle, then the animal suffers from lower motor disease. Several specific signs indicate that lower motor neuron disease exists (Fig. 2-9).

These are independent of the cause of the disease (inflammation, compression, physical disconnection).
An obvious indication of lower motor neuronal disease is the atrophy of the muscle in the area affected, due to inactivity. In some cases there is also a loss of sensory capacity in the area affected.