- The role of the spinal cord is secondary to that of the brain.
- Circuits exist in the spinal cord, however, that process sensory information and are capable of generating complex motor activity.

- **Organization of the spinal cord for motor functions:**
  - **Anterior (ventral) horn motor neurons:**
    - Present at levels of the spinal cord.
    - Innervate skeletal striated muscles. Note that a motor neuron and all the muscle fibers it innervates are referred to collectively as a (motor unit).
    - There are two types of motor neurons in the ventral horn:
      - *Alpha motor neurons*: myelinated axons, 14 micrometers in diameter, high conduction velocity.
      - *Gamma motor neurons*: 5 micrometers in diameter, low conduction velocity.
  - **Interneuron:**
    - They are 30 times more numerous than motor neurons.
    - Highly excitable.
    - Spontaneous firing rates as high as 1500/sec.
    - They receive the bulk of synaptic input that reaches the spinal cord, as either incoming sensory information or as signals descending from higher centers in the brain.
    - *Renshaw cell*: a type of interneuron. It receives input from collateral branches of motor neuron axons and then, via its own axonal system, provides inhibitory connections with the same or neighboring motor neurons.

- **Muscle sensory receptors (muscle spindles and Golgi tendon organs) and their roles in muscle control:**
  - **Receptor function of the muscle spindle:**
    - The sensory feedback from muscles include:
      - *Current length* of the muscle. The length value is derived from a muscle spindle.
      - *Current tension* in the muscle. Tension is signaled by a Golgi tendon organ.
    - *Muscle spindle:*
      - 3-10 mm in length.
      - Consists of 3-12 thin intrafusal muscle fibers.
      - Each intrafusal muscle fiber is attached at its distal ends to the associated extrafusal skeletal muscle.
      - The central region of each intrafusal fiber is devoid of actin-myosin contractile elements (they are not present) and, instead, forms a capsule containing several nuclei. If the nuclei are arranged linearly
the fiber is called nuclear chain fiber. If the nuclei are arranged in aggregates or clusters the fiber is called nuclear bag fiber.

- The distally located contractile elements of each intrafusal fiber are innervated by relatively small gamma motor neuron axons.
- 2 types of sensory fibers are associated with muscle spindle intrafusal fibers:
  - *Primary ending*: type Ia myelinated primary sensory fibers, diameter of 17 micrometers, rapid conduction velocity of 70-120 m/sec.
  - *Secondary ending*: type II lightly myelinated fibers, diameter of 8 micrometers, conducts at a slower velocity.

Note: the primary ending wraps itself around the central (nuclear) region of both a nuclear bag and a nuclear chain intrafusal fiber, whereas the secondary ending forms numerous small terminal branches that cluster around the nuclear region of only the nuclear chain intrafusal fibers.
- Dynamic and static responses of the muscle spindle:
  - **Static response**: central region of muscle spindle slowly stretched → number of impulses in both the primary and secondary endings increase in proportion to the degree of stretch. This response is mediated by nuclear chain fibers.
  - **Dynamic response**: length of muscle spindle suddenly increased → primary sensory fibers will show strong response. This response is mediated by nuclear bag fibers.

- Control of intensity of the static and dynamic responses by the gamma motor neurons:
  - Gamma motor neurons distributed to nuclear bag fibers are called dynamic.
  - Those distributing to nuclear chain fibers are static.

- Muscle stretch reflex:
  - Type Ia sensory fibers enter the spinal cord through the dorsal roots and give rise to branches that either terminate in the cord near their level of entry or ascend to the brain.
  - Those that terminate in the cord synapse directly with alpha motor neurons in the ventral horn, which innervate extrafusal fibers.
  - This reflex has 2 components: dynamic phase and static phase.
  - An important function of the stretch reflex is its damping effect on jerky movements.
  - In the absence of normally functioning spindle sensory mechanisms, an unusual repetitive contraction of muscles called clonus appears. Clonus is alternating contraction of the agonist and antagonist muscles crossing a joint. Often prominent at the ankle.
  - **Testing the stretch reflex**: tapping on the patellar tendon at the knee stretches spindles in the quadriceps and normally elicits a reflex contraction of that muscle group (stretch reflex), which produces a knee jerk.

- Role of the muscle spindle in voluntary motor activity:
  - 31% of the axons distributing to any given muscle are from gamma motor neurons.
  - The stimulation of gamma motor neurons during contraction of a muscle maintains the sensitivity of the spindle and prevents it from going “slack” and stopping its output.

- Golgi tendon reflex:
  - **Golgi tendon organ**: encapsulated receptor through which a small bundle of muscle tendon fibers pass just prior to their bony insertion. It is stimulated when the tension imposed by muscle contraction is increased.
  - The tendon organ produces inhibition of the motor neurons innervating the muscle with which the tendon organ is associated.

- **Withdrawal reflex (flexor reflex):**
  - Elicited by pain receptors.
  - The sensory fibers that carry these signals terminate on the pool of spinal cord interneurons, most of which provide excitatory input to the appropriate ventral horn motor neurons, whereas others inhibit motor neurons that innervate antagonistic muscles. The latter mechanism is called reciprocal inhibition.
- **Crossed extensor reflex:**
  - Occurs in conjunction with the flexor reflex.
  - For example, withdrawing the foot might require that the other foot support the entire body.
  - In this situation, interneurons that receive the incoming pain signal from one foot can project across the medline to excite the appropriate contralateral motor neurons to support the body; often they are extensor motor neurons.

- **Reflexes of posture and locomotion:**
  - Pressure on a footpad causes the limb to be extended against the applied pressure (positive supportive reaction).
  - When an animal with cervical cord transaction is placed on its side, it tries to raise itself to a standing position (cord righting reflex).
  - If a cord-transected animal is suspended on a treadmill so each of the limbs can touch the surface of the treadmill, all 4 limbs move in a synchronous and coordinated manner as if the animal was trying to walk on the treadmill.
- **Spinal cord transaction and spinal shock:**
  - When the spinal cord is transected, all cord functions below the transaction become substantially depressed; this is referred to as spinal shock.
  - The affected neurons gradually regain their excitability as they reorganize and adapt to the new levels of reduced synaptic input.
  - **Common symptoms that appear during spinal shock:**
    - Arterial blood pressure may fall significantly.
    - All skeletal muscle reflexes are nonfunctional.
    - Sacral autonomic reflexes that regulate bladder and bowel function may be suppressed for several weeks.