

CHAPTER 10

THE SOMATOSENSORY SYSTEM

10.1. SOMATOSENSORY MODALITIES

"Somatosensory" is really a catch-all term to designate senses other than vision, hearing, balance, taste and smell. Receptors that could be designated "somatosensory" are distributed all over the body rather than concentrated at specific locations. The different types of receptors respond to many different kinds of stimuli.

The somatosensory system includes at least 4 distinct modalities and many submodalities. These include the *cutaneous senses*, such as touch, pressure, vibration and temperature; *proprioception*, or sensing of body position; *kinesthesia*, or body movement, as well as *pain, tickle, and itch*.

10.2. THE CUTANEOUS SENSES

10.2.1. Cutaneous receptor types

The skin contains a number of different types of sensory receptors. Each receptor is specialized to convey certain information.

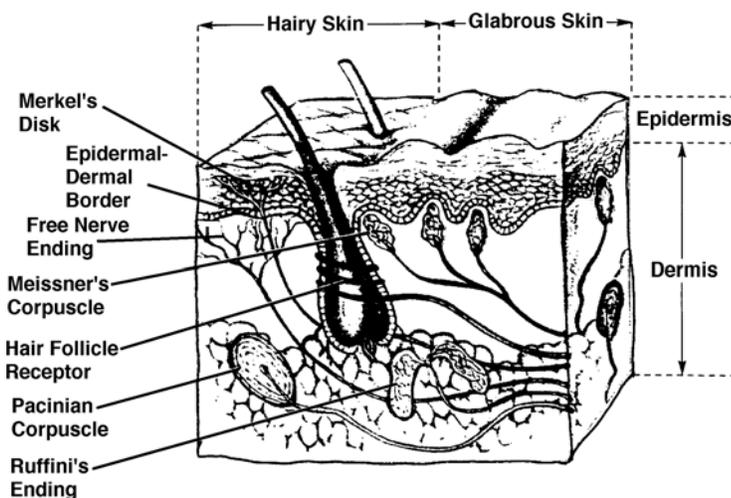


Figure 10-1. Section through the skin showing the different types of cutaneous receptors.

Cutaneous receptors can take many forms, but all share some features in common. The *Pacinian corpuscle* is one example of a cutaneous receptor, and illustrates some common features.

10.2.1.1. General structure of cutaneous receptors. Pacinian corpuscles are large receptors, located deep within the skin. Each cutaneous receptor (including Pacinian corpuscles) contains a nerve ending that is, essentially, the dendrite of a neuron whose cell body is located in a ganglion near the spinal cord, the *dorsal root ganglion*. The nerve ending of the Pacinian corpuscle is wrapped in many layers of specialized connective tissue.

Other cutaneous receptors include *Meissner's corpuscles*, *Merkel's disks*, *Ruffini cylinders*, and *free nerve endings*. The first three (*encapsulated endings*) are similar in structure to Pacinian corpuscles in that the nerve endings have a connective tissue covering, the mechanical properties of which determine the dynamic properties of the response (i.e., whether it is rapidly adapting or slowly adapting, whether it responds best to fast or slow rates of stimulation, whether it responds best to pressure or to stretch, etc.). Free nerve endings are stimulated by a variety of means including mechanical deformation, heat or cold, and various chemical substances. All are similar in that their cell body is located in the dorsal root ganglion.

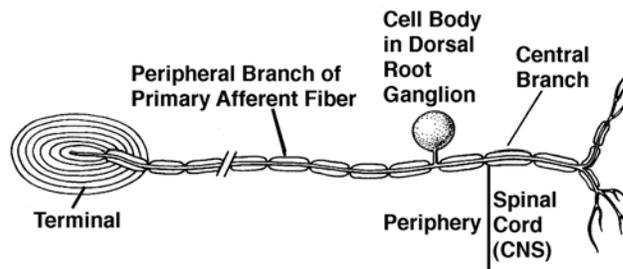


Figure 10-2. The terminal of the Pacinian corpuscle (left) consists of a nerve ending wrapped in a multilayered connective tissue sheath. The nerve ending is the end of a myelinated process (the primary afferent fiber) that extends between the receptor and the cell body in the dorsal root ganglion. Another myelinated process (the central branch) extends from the cell body in the ganglion to terminate in the spinal cord.

Hairy skin also contains *hair follicle mechanoreceptors*, in which a nerve ending is wrapped around the base of a hair so that movement of the hair stimulates the nerve ending. Animals' whiskers are specialized variations of hair follicle receptors. The whiskers are an extremely important source of sensory information in some species such as mice, rats and cats.

Thought question: Free nerve endings often convey a sensation of pain, and are activated by a variety of different stimuli including deformation of the surrounding tissue, extreme heat, extreme cold, and chemical irritants that originate externally (e.g., strong acid) or internally (substances released by damaged tissue). Given what you know about neurons and transduction, how do you think the free nerve endings are able to respond to all these different stimulus types? Why is it advantageous for free nerve endings to respond to so many different types of stimuli?

10.2.1.2. Transduction in cutaneous receptors. Deformation of the connective tissue covering of the nerve ending or movement of other tissue associated with the nerve ending causes activation of mechanically-gated ion channels, leading to depolarization of the receptor. If the

depolarization is great enough, the cell produces an action potential that is transmitted to the central nervous system.

10.2.1.3. Adaptation in cutaneous receptors. Some cutaneous receptors such as Pacinian corpuscles adapt rapidly because of the mechanical characteristics of the connective tissue sheath. *Rapid adaptation* means that there is no response to sustained pressure, only to changes in pressure (either an increase or a decrease). Other cutaneous receptors, such as Merkel's disks, adapt slowly. *Slow adaptation* means that the receptor continues to respond to pressure for as long as it is sustained, within some reasonable time frame. If pressure is continuous, such as wearing a tight watch band all day, even the slowly-adapting receptors will eventually adapt.

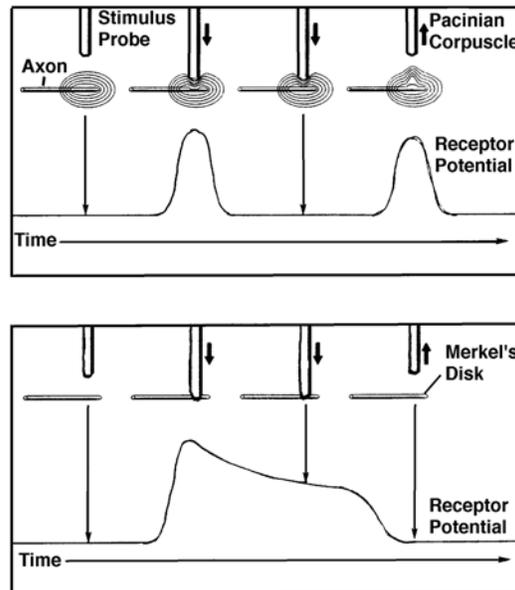


Figure 10-3. Rapid adaptation in a Pacinian corpuscle (top) compared with slow adaptation in Merkel's disks (bottom). When pressure is applied, the membrane potential of the rapidly adapting receptor goes back to resting level even though the pressure continues to be applied. In the slowly adapting receptor, the membrane potential changes and remains at or near the new level for as long as the pressure is maintained.

10.2.1.4. Receptive fields of cutaneous receptors. The receptive field of a cutaneous receptor is that portion of the skin which, when stimulated, affects the activity or state of the receptor. Some types of cutaneous receptors, e.g., Pacinian corpuscles, have large receptive fields and poor spatial resolution. Others, e.g., Meissner's corpuscles, have small receptive fields and good spatial resolution.

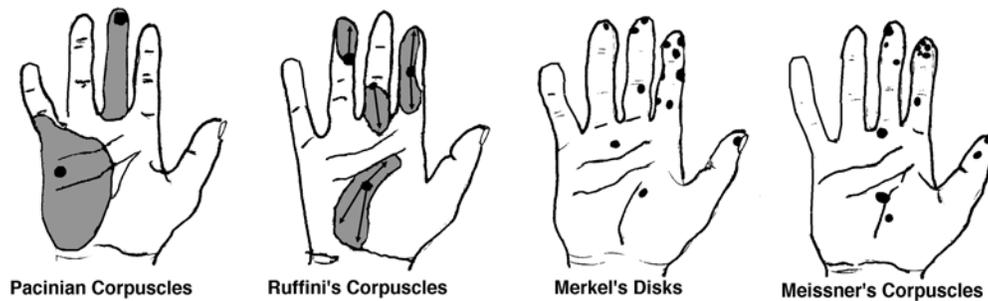


Figure 10-4. Pacinian and Ruffini corpuscles (left) have large receptive fields (shaded areas) and poor spatial resolution. In contrast, Merkel's discs and Meissner's corpuscles (right) have small receptive fields and good spatial resolution. Note that the Ruffini corpuscles also respond to stretching of the skin in the direction of the arrows.

10.2.1.5. Responses of cutaneous receptors to different patterns of stimulation. Because of the characteristics of the tissue surrounding the nerve endings in the skin and the ion channels present in the nerve endings, different types of cutaneous receptors are most sensitive to different patterns of vibration or changes in pressure. Some respond best to high rates of vibration and others to low rates.

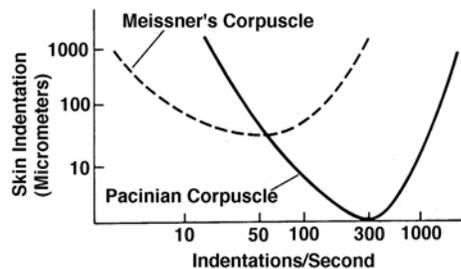


Figure 10-5. Tuning curves for two different types of mechanoreceptors showing their threshold for responding (amount of indentation necessary to elicit a response, vertical axis) as a function of rate of indentation (horizontal axis). The Pacinian corpuscle (solid line) responds best to higher rates of indentation (300/second); the Meissner's corpuscle responds best to lower rates (about 50/second).

10.2. CENTRAL CONNECTIONS OF CUTANEOUS RECEPTORS

10.2.1. The peripheral nerves and ganglia.

The nerve fibers that innervate skin receptors have their cell bodies in the *dorsal root ganglion*, a group of neuron cell bodies near the spinal cord. The axons of dorsal root ganglion cells project in to the spinal cord, where they synapse with neurons in the *dorsal horn of the grey matter*.

Nerves from different parts of the body enter the spinal cord at different places. Sections of the body can be identified based on which spinal segment innervates them.

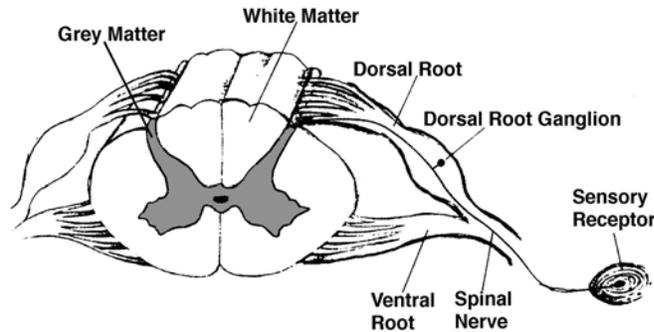


Figure 10-6. The dorsal root ganglion contains the cell bodies of nerve fibers that innervate receptors on the skin, muscles, tendons, etc. The dorsal root ganglion cells send axons to neurons in the dorsal horn of the grey matter in the spinal cord.

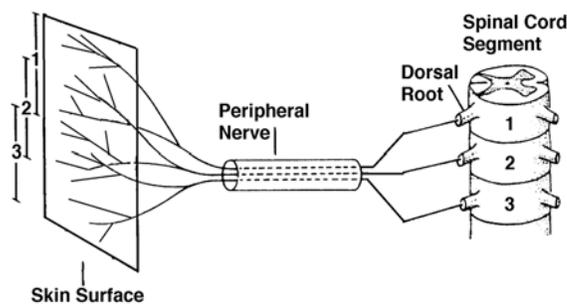


Figure 10-7. Each segment of the spinal cord receives innervation from a different part of the body. Here, three fibers in a peripheral nerve branch to receive input from three different, but overlapping, areas on the skin surface, indicated by the vertical lines at left. Each nerve fiber enters a different segment of the spinal cord.

10.2.2. Spinal cord and brain pathways.

Touch and proprioceptive information is transmitted to the thalamus via large diameter fibers that run in the *dorsal columns* of the spinal cord and *medial lemniscus* in the brain. Information about *temperature and pain* is transmitted to the thalamus via small diameter fibers that run in the *spinothalamic tracts* of the spinal cord and *anterolateral pathway* in the brain.

From the thalamus (ventral posterior nucleus), information is sent to the primary somatosensory cortex.

Nerve fibers conveying different types of sensory information have different diameters. Large-diameter, myelinated nerves such as those from the cutaneous pressure or vibration

receptors conduct information rapidly. Small unmyelinated nerves from the free nerve endings conduct information slowly.

10.3. OTHER SOMATOSENSORY MODALITIES

10.3.1. Proprioception

Proprioception refers to the sense of body position. Muscles and tendons have receptors that respond to stretch or tension. Activation of these receptors signals the position of limbs and other parts of the body as well as the degree of contraction and weighting of muscles. Reflexes mediated directly through the spinal cord help use this information to control muscle contractions and thereby maintain body position.

10.3.2. Perception of temperature

The skin contains receptors that are activated by warmth, and others that are activated by cold. Cold receptors are also activated at very high temperatures, leading to the perception of "paradoxical cold".

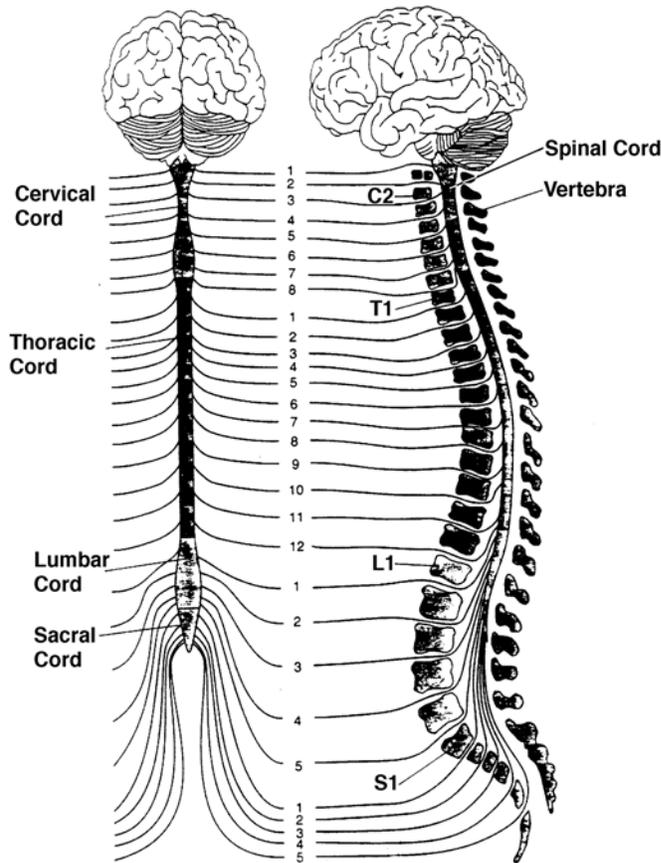


Figure 10-8. Each vertebra of the spine has a corresponding segment of the spinal cord with a name and number that indicates its position in the cervical (neck) region, the thoracic (chest) region, lumbar (middle back) region, or sacral (lower back) region. Each spinal cord segment receives peripheral sensory innervation through the dorsal root of the corresponding spinal nerve.

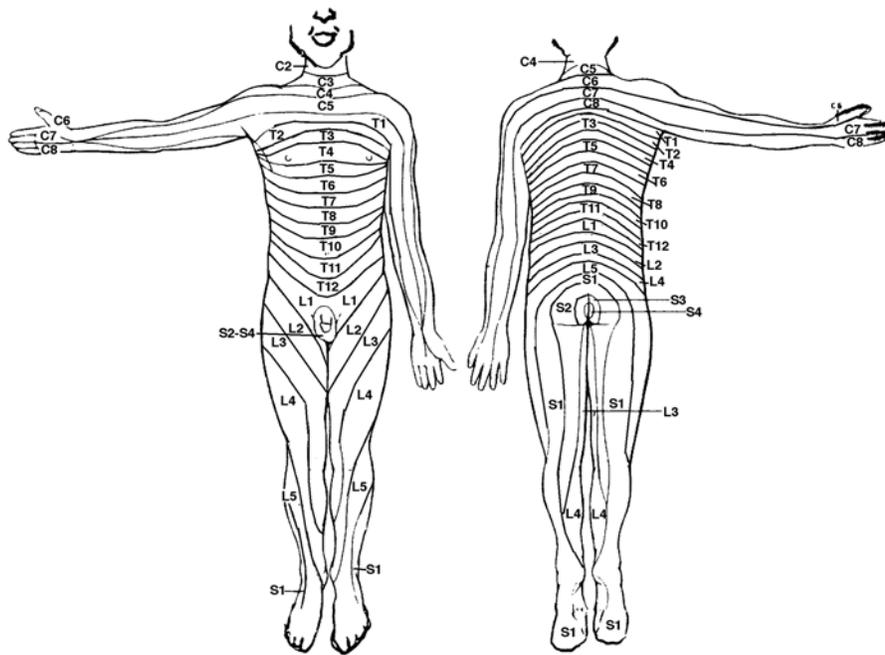


Figure 10-9. Each spinal nerve innervates a specific part of the body surface.

Sensory Axons	A α	A β	A δ	C
Motor Axons	Group I	II	III	IV
Diameter (μm)	13-20	6-12	1-5	0.2-1.5
Speed (m/sec)	80-120	35-75	5-30	0.5-2
Sensory Receptors	Muscle Proprioceptors	Skin Mechano-receptors	Pain, Temperature	Temperature, Pain, Itch

Figure 10-10. Nerve fibers with different diameters (partly due to myelination or lack thereof) conduct action potentials at different speeds.

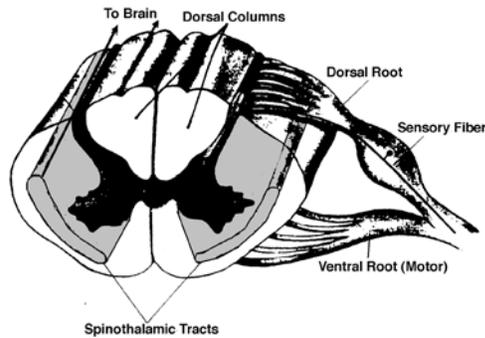


Figure 10-11. Cross section of the spinal cord showing the dorsal root ganglion, dorsal columns and spinothalamic tracts.

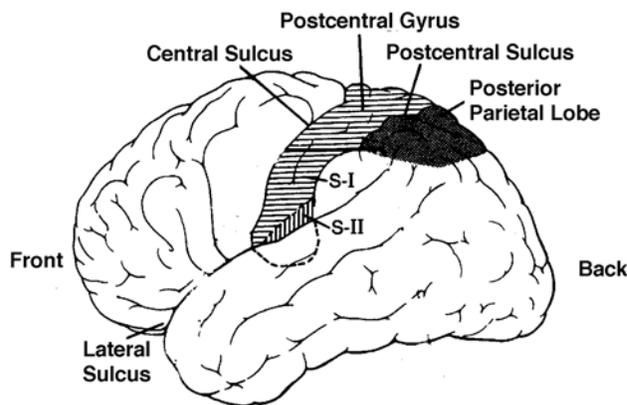


Figure 10-12. Side view of the brain shows the location of primary somatosensory cortex (SI), secondary somatosensory areas (SII), and posterior parietal area. The somatosensory area extends into the sulcus below the overlying temporal lobe in the region indicated by the dashed line.

10.3.3. Pain

As mentioned above, the sensation of pain is caused by activation of very small diameter nerve endings. When tissue is damaged, chemical substances are released that stimulate these fibers.

Many different chemical substances (e.g., aspirin) have an *analgesic* (pain-killing) effect. Different analgesics act through different mechanisms. In addition to chemicals of external origin, the body is capable of producing its own pain modulating substances. *Endorphins* are analgesic chemicals produced by the body under conditions of stress, when performance is necessary even under conditions that would normally cause pain or discomfort.

Pain can be modified by nonpainful sensory stimuli such as rubbing (pressure), heat or cold, or chemical stimuli such as capsaicin (red pepper). The modification of pain by cutaneous stimulation is the basis of treatments such as acupuncture.

The relationships between pain pathways and parts of the body are not always straightforward. The phenomenon of *referred pain* illustrates the complicated nature of the pain pathways. In referred pain, pain that originates in an internal organ is perceived as originating in a part of the body surface that may be far removed from the real origin of the pain.

Obviously, the use of pain symptoms for diagnosis of injury or disease, and the treatment of pain is a complicated science, and an area that even today is not fully understood.

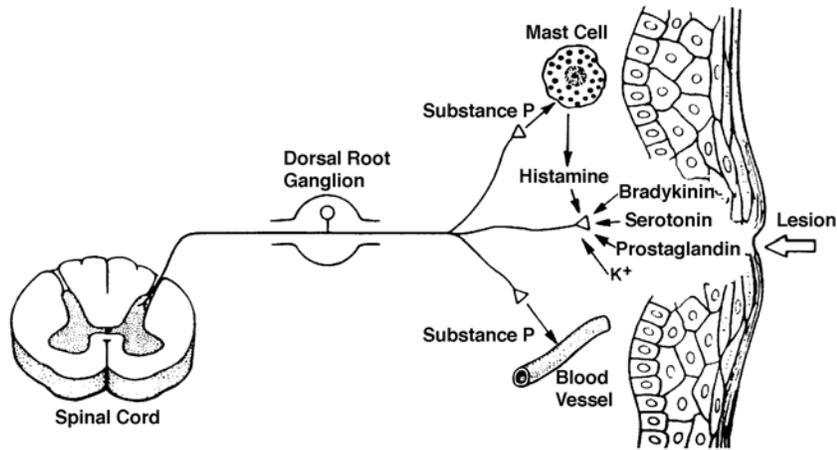


Figure 10-13. Damage to tissue causes release of chemicals such as bradykinin, serotonin, prostaglandin and histamine. These stimulate free nerve endings that project to the spinal cord via a cell body in the dorsal root ganglion.

Thought question: Patients who have had an arm or leg amputated often experience a phenomenon called "phantom limb" in which they feel that the amputated limb is still present. They often feel pain associated with the non-existent limb. Why do you think this occurs?

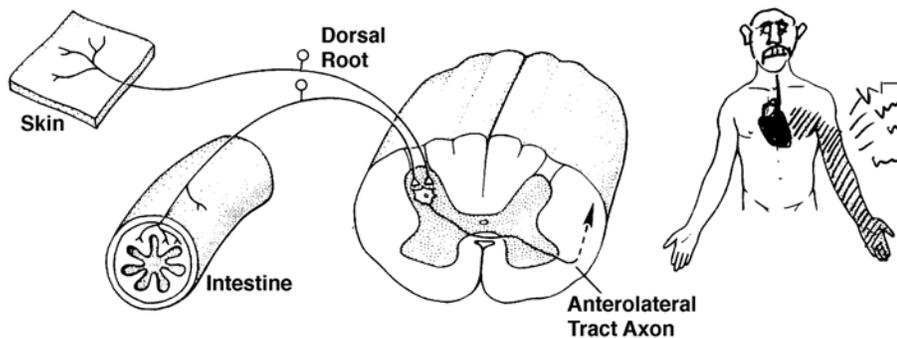


Figure 10-14. Referred pain occurs because nerves that innervate specific parts of the skin terminate in the same region of the spinal cord as nerves that innervate internal organs. For example, a single region of the spinal cord receives input from the skin of the trunk and the intestine (left). Another region of the spinal cord receives input from the heart, part of the chest, and the left arm. The man having a heart attack (right) feels pain in his chest and arm.