Muscle Tissue

Muscle tissue is composed of differentiated cells containing contractile proteins. The structural biology of these proteins generates the forces necessary for cellular contraction, which drives movement within certain organs and the body as a whole. Most muscle cells are of mesodermal origin, and they are differentiated mainly by a gradual process of lengthening, with simultaneous synthesis of myofibrillar proteins.

Three types of muscle tissue in mammals can be distinguished on the basis of morphological and functional characteristics, and each type of muscle tissue has a structure adapted to its physiological role. **Skeletal muscle** is composed of bundles of very long, cylindrical, multinucleated cells that show cross-striations. Their contraction is quick, forceful, and usually under voluntary control. It is caused by the interaction of thin actin filaments and thick myosin filaments whose molecular configuration allows them to slide upon one another. The forces necessary for sliding are generated by weak interactions in the bridges that bind actin to myosin. **Cardiac muscle** also has cross-striations and is composed of elongated, branched individual cells that lie parallel to each other. At sites of end-to-end contact are the **intercalated disks,** structures found only in cardiac muscle. Contraction of cardiac muscle is involuntary, vigorous, and rhythmic. **Smooth muscle** consists of collections of fusiform cells that do not show cross-striations. Their contraction process is slow and not subject to voluntary control.

Some muscle cell organelles have names that differ from their counterparts in other cells. The cytoplasm of muscle cells is called sarcoplasm, and the smooth endoplasmic reticulum is called sarcoplasmic reticulum. The sarcolemma is the cell membrane, or plasmalemma.

Skeletal Muscle

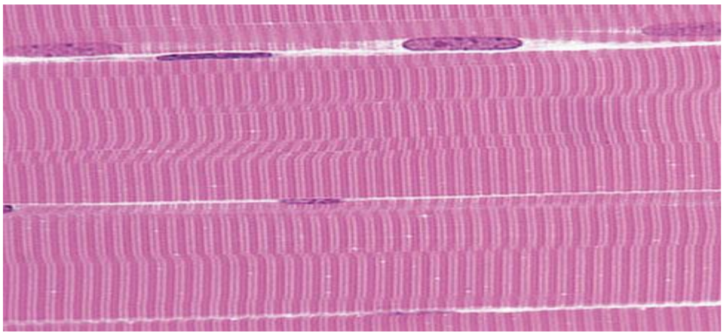
Skeletal muscle consists of **muscle fibers,** bundles of very long (up to 30 cm) cylindrical multinucleated cells. Multinucleation results from the fusion of embryonic mononucleated myoblasts. The oval nuclei are usually found at the periphery of the cell under the cell membrane. This characteristic nuclear location is helpful in distinguishing skeletal muscle from cardiac and smooth muscle, both of which have centrally located nuclei.

Organization of Skeletal Muscle

The masses of fibers that make up the various types of muscle are not grouped in random fashion but are arranged in regular bundles surrounded by the **epimysium**, an external sheath of dense connective tissue surrounding the entire muscle. From the epimysium, thin septa of connective tissue extend inward, surrounding the bundles of fibers within a muscle. The connective tissue around each bundle of muscle fibers is called the **perimysium**. Each muscle fiber is itself surrounded by a delicate layer of connective tissue, the **endomysium**, composed mainly of a basal lamina and reticular fibers.

One of the most important roles of connective tissue is to mechanically transmit the forces generated by contracting muscle cells, because in most instances, individual muscle cells do not extend from one end of a muscle to the other.

Blood vessels penetrate the muscle within the connective tissue septa and form a rich capillary network that runs between and parallel to the muscle fibers. The capillaries are of the continuous type, and lymphatic vessels are found in the connective tissue

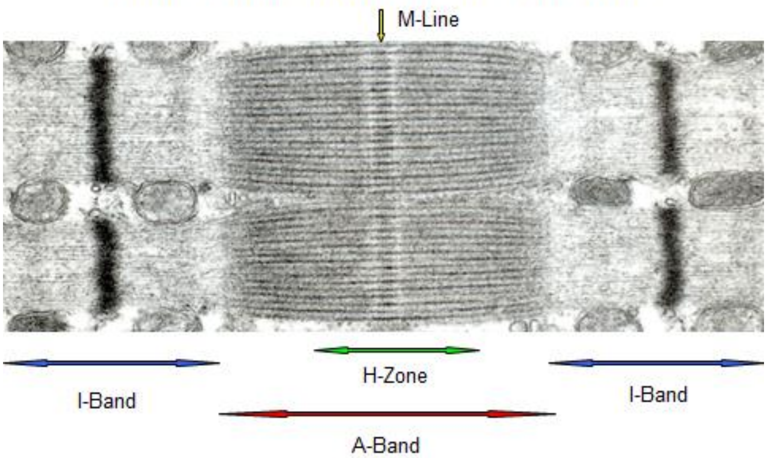


Organization of Skeletal Muscle Fibers

As observed with the light microscope, longitudinally sectioned muscle fibers show cross-striations of alternating light and dark bands. The darker bands are called **A bands**; the lighter bands are called **I bands**. In the electron microscope, each I band is bisected by a dark transverse line, the **Z line.** The smallest repetitive subunit of the contractile apparatus, the **sarcomere**, extends from Z line to Z line.

The sarcoplasm is filled with long cylindrical filamentous bundles called **myofibrils.** The myofibrils, and run parallel to the long axis of the muscle fiber, consist of an end-to-end chainlike arrangement of sarcomeres. The lateral registration of sarcomeres in adjacent myofibrils causes the entire muscle fiber to exhibit a characteristic pattern of transverse striations.Striated muscle filaments contain several proteins; the four main proteins are **actin**, tropomyosin, troponin, and **myosin**.

TEM of a Skeletal Muscle Sarcomere



Cardiac Muscle

During embryonic development, the splanchnic mesoderm cells of the primitive heart tube align into chainlike arrays. Rather than fusing into syncytial cells, as in the development of skeletal muscle, cardiac cells form complex junctions between their extended processes. Cells within a chain often bifurcate, or branch, and bind to cells in adjacent chains. Consequently, the heart consists of tightly knit bundles of cells, interwoven in a fashion that provides for a characteristic wave of contraction that leads to a wringing out of the heart ventricles. They exhibit a cross-striated banding pattern identical to that of skeletal muscle. Unlike multinucleated skeletal muscle, however, each cardiac muscle cell possesses only one or two centrally located pale-staining nuclei. Surrounding the muscle cells is a delicate sheath of endomysial connective tissue containing a rich capillary network.

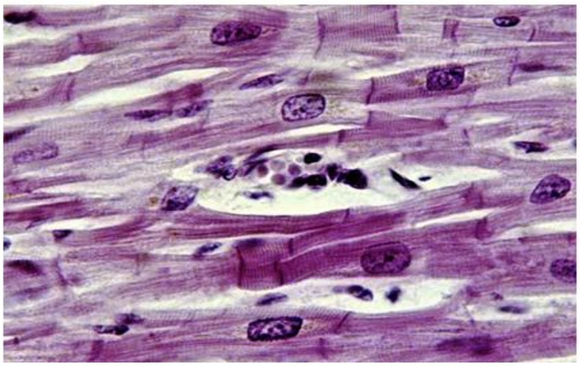
A unique and distinguishing characteristic of cardiac muscle is the presence of dark-staining transverse lines that cross the chains of cardiac cells at irregular intervals. These **intercalated disks** represent junctional complexes found at the interface between adjacent cardiac muscle cells. On the lateral portions of the disk, **gap junctions** provide ionic continuity between adjacent cells. The significance of ionic coupling is that chains of individual cells act as a syncytium, allowing the signal to contract to pass in a wave from cell to cell.

The sarcoplasmic reticulum is not as well developed and wanders irregularly through the myofilaments. As a consequence, discrete myofibrillar bundles are not present.

Cardiac muscle cells contain numerous mitochondria, which occupy 40% or more of the cytoplasmic volume, reflecting the need for continuous aerobic metabolism in heart muscle. By comparison, only about 2% of skeletal muscle fiber is occupied by mitochondria. Fatty acids, transported to cardiac muscle cells by lipoproteins, are the major fuel of the heart. Fatty acids are stored as triglycerides in the numerous lipid droplets seen in cardiac muscle cells. A small amount of glycogen is present and can be broken down to glucose and used for energy production during periods of stress. Lipofuscin pigment granules, often seen in long-lived cells, are found near the nuclear poles of cardiac muscle cells.

The rich autonomic nerve supply to the heart and the rhythmic impulse-generating and ›nducting structures.

High mag of Cardiac Muscle



Smooth Muscle

Smooth muscle is composed of elongated, nonstriated cells, each of which is enclosed by a basal mina and a network of reticular fibers.

Smooth muscle cells are fusiform, ie, they are largest at their midpoints and taper toward their ends. During pregnancy, uterine smooth muscle cells undergo a marked increase in size and number. Each cell has a single nucleus located in the center of the broadest part of the cell. To achieve the tightest packing, the narrow part of one cell lies adjacent to the broad parts of neighboring cells. Such an arrangement viewed in cross section shows a range of diameters, with only the largest profiles containing a nucleus. The borders of the cell become scalloped when smooth muscle contracts, and the nucleus becomes folded or has the appearance of a corkscrew.

Concentrated at the poles of the nucleus are mitochondria, polyribosomes, cisternae of rough endoplasmic reticulum, and the Golgi complex. Pinocytotic vesicles are frequent near the cell surface.

A rudimentary sarcoplasmic reticulum is present; it consists of a closed system of membranes, similar to the sarcoplasmic reticulum of striated muscle. T tubules are not present in smooth muscle cells.

The characteristic contractile activity of smooth muscle is related to the structure and organization of its actin and myosin filaments, which do not exhibit the paracrystalline organization present in striated muscles. In smooth muscle cells, bundles of myofilaments crisscross obliquely through the cell, forming a latticelike network.

The degree of innervation in a particular bundle of smooth muscle depends on the function and the size of that muscle. Smooth muscle is innervated by both sympathetic and parasympathetic nerves of the autonomic system. Elaborate neuromuscular junctions such as those in skeletal muscle are not present in smooth muscle. Frequently, autonomic nerve axons terminate in a series of dilatations in the endomysial connective tissue.

In general, smooth muscle occurs in large sheets such as those found in the walls of hollow viscera, eg, the intestines, uterus, and ureters. Their cells possess abundant gap junctions and a relatively poor nerve supply. These muscles function in syncytial fashion and are called **visceral smooth muscles.** In contrast, the **multiunit smooth muscles** have a rich innervation and can produce precise and graded contractions such as those occurring in the iris of the eye.