Muscle tissue

Illustration of the Neuromuscular Junction

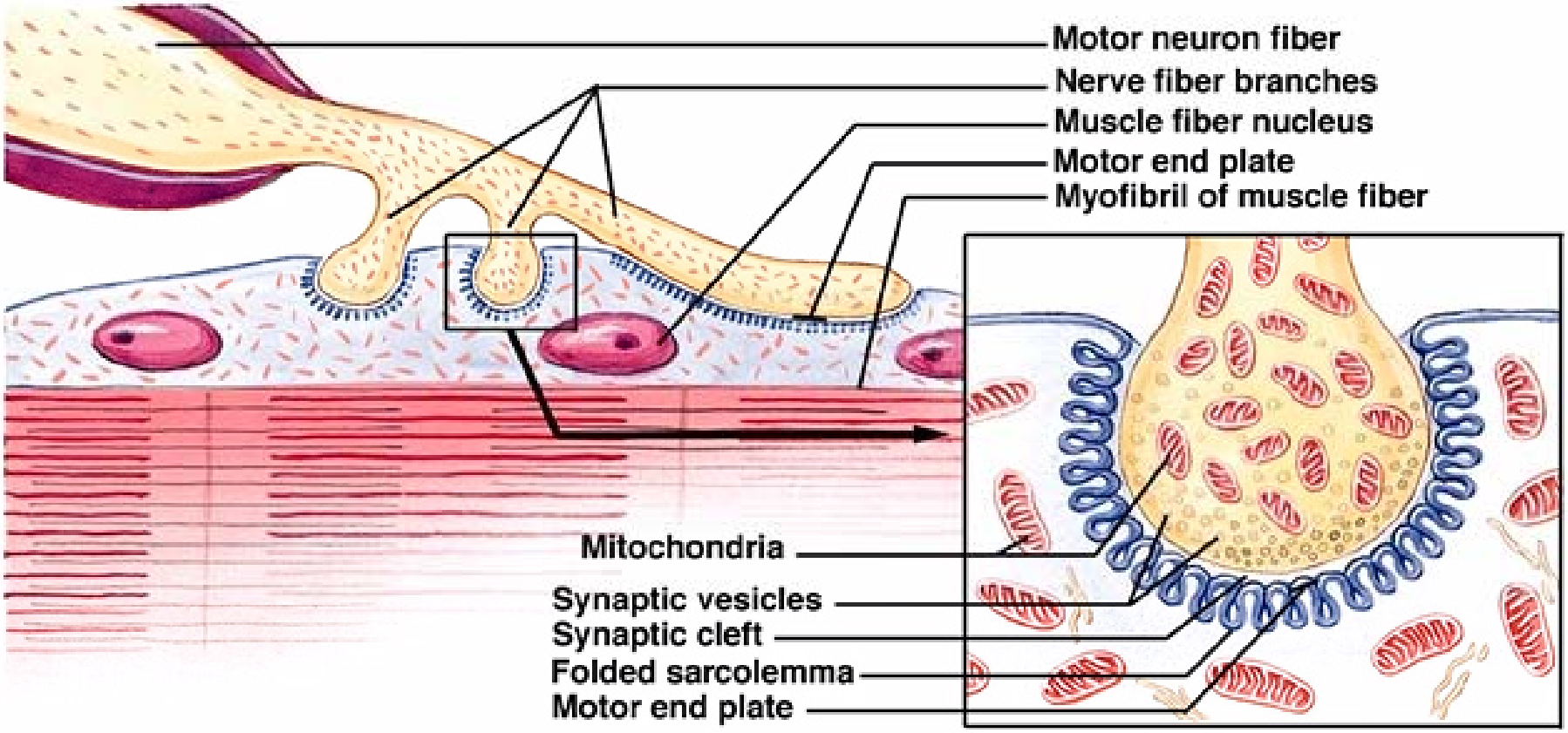
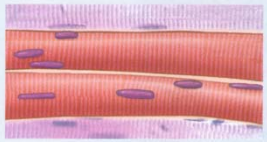
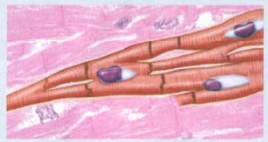
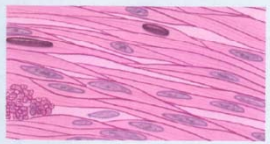


TABLE 10–1 Important comparisons of the three types of muscle.

	Skeletal Muscle	Cardiac Muscle	Smooth Muscle
			
Fibers	Single multinucleated cells	Aligned cells in branching arrangement	Single small, closely packed fusiform cells
Cell/fiber shape and size	Cylindrical, 10-100 μm diameter, many cm long	Cylindrical, 10-20 μm diameter, 50-100 μm long	Fusiform, diameter 0.2-10 μm, length 50-200 μm
Striations	Present	Present	Absent
Location of nuclei	Peripheral, adjacent to sarcolemma	Central	Central, at widest part of cell
T tubules	Center of triads at A-I junctions	In diads at Z discs	Absent; caveolae may be functionally similar
Sarcoplasmic reticulum (SR)	Well-developed, with two terminal cisterns per sarcomere in triads with T tubule	Less well-developed, one small terminal cistern per sarcomere in diad with T tubule	Irregular smooth ER without distinctive organization
Special structural features	Very well-organized sarcomeres, SR, and transverse tubule system	Intercalated discs joining cell, with many adherent and gap junctions	Gap junctions, caveolae, dense bodies
Control of contraction	Troponin C binds Ca^{2+}, moving tropomyosin and exposing actin for myosin binding	Similar to that of skeletal muscle	Actin-myosin binding occurs with myosin phosphorylation by MLCK triggered when calmodulin binds Ca^{2+}
Connective tissue organization	Endomysium, perimysium, and epimysium	Endomysium; subendocardial and subpericardial CT layers	Endomysium and less-organized CT sheaths
Major locations	Skeletal muscles, tongue, diaphragm, eyes, and upper esophagus	Heart	Blood vessels, digestive and respiratory tracts, uterus, bladder, and other organs
Key function	Voluntary movements	Automatic (involuntary) pumping of blood	Involuntary movements
Efferent innervation	Motor	Autonomic	Autonomic
Contractions	All-or-none, triggered at motor end plates	All-or-none, intrinsic (beginning at nodes of conducting fibers)	Partial, slow, often spontaneous, wavelike and rhythmic
Cell response to increased load	Hypertrophy (increase in fiber size)	Hypertrophy	Hypertrophy and hyperplasia (increase in cell/fiber number)
Capacity for regeneration	Limited, involving satellite cells mainly	Very poor	Good, involving mitotic activity of muscle cells

Muscle spindle & tendon organ

- Proprioreceptor

Sensory organ

- Muscular spindle

2Stretch detector (fascicles)

2mm long & 0.1 mm wide

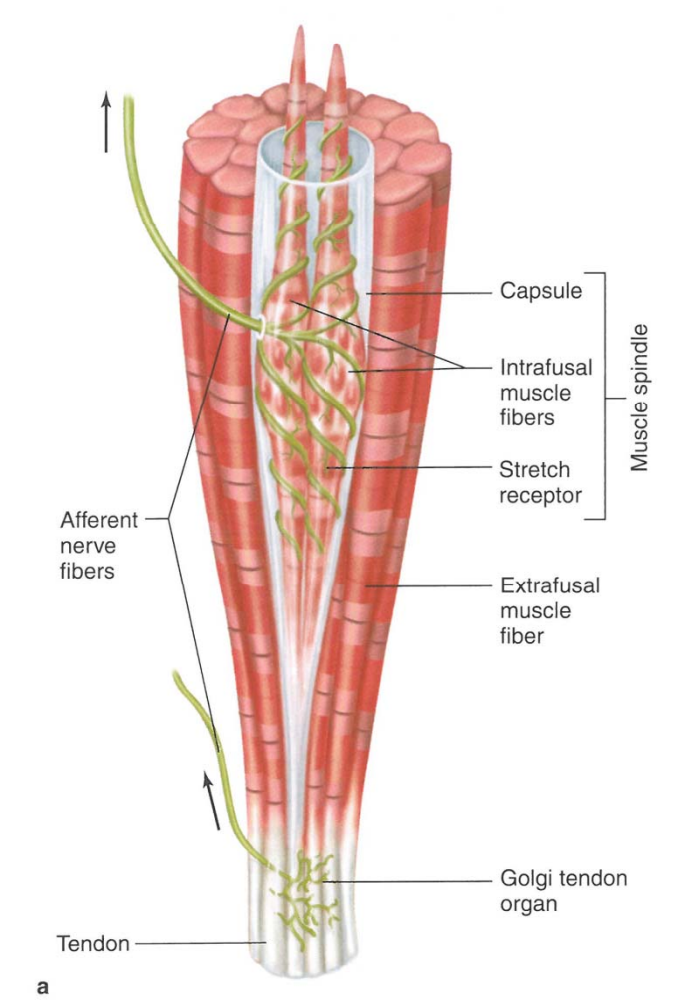
Encapsulated by modified perimysium

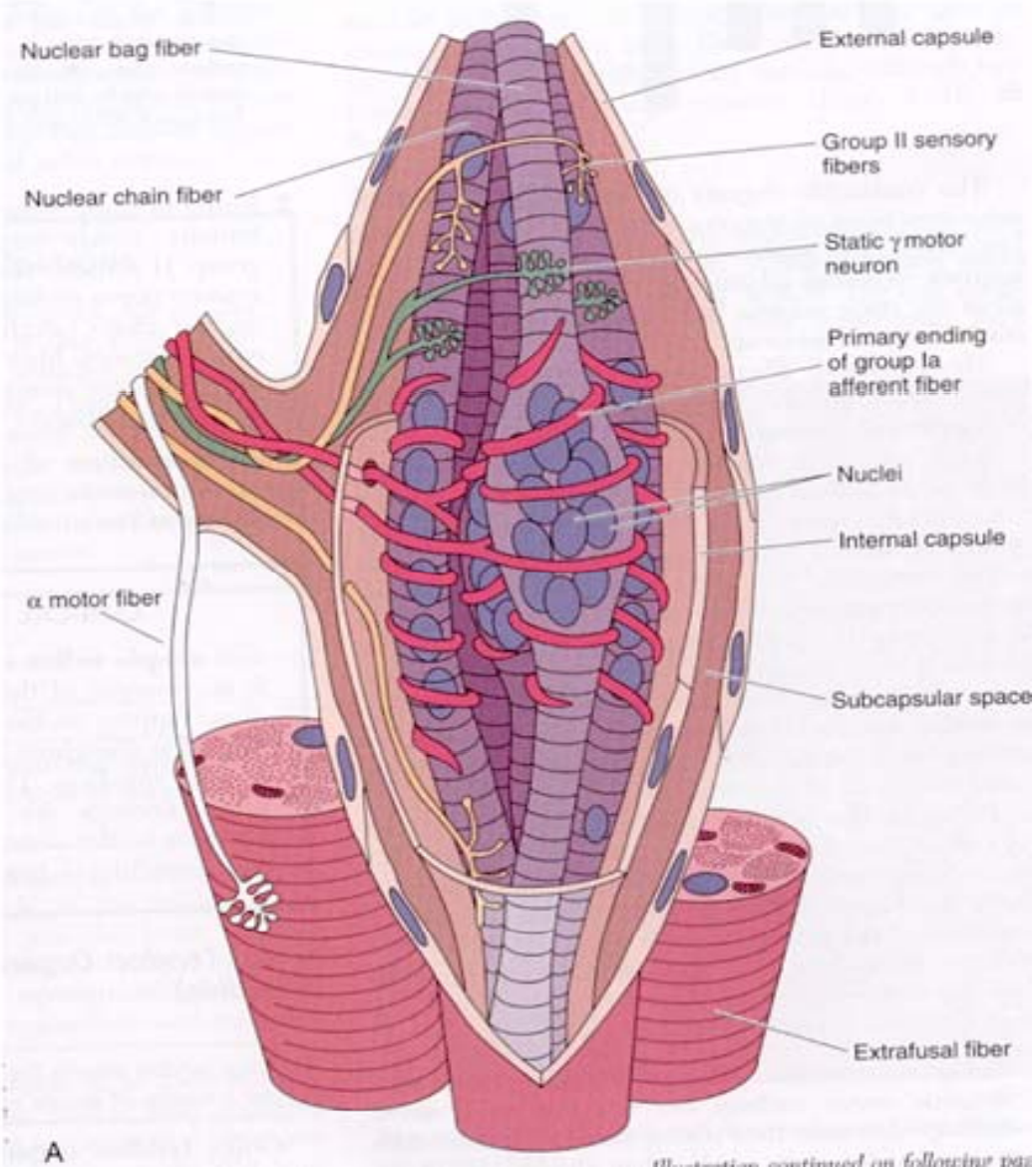
Concetric layers of flattened cells

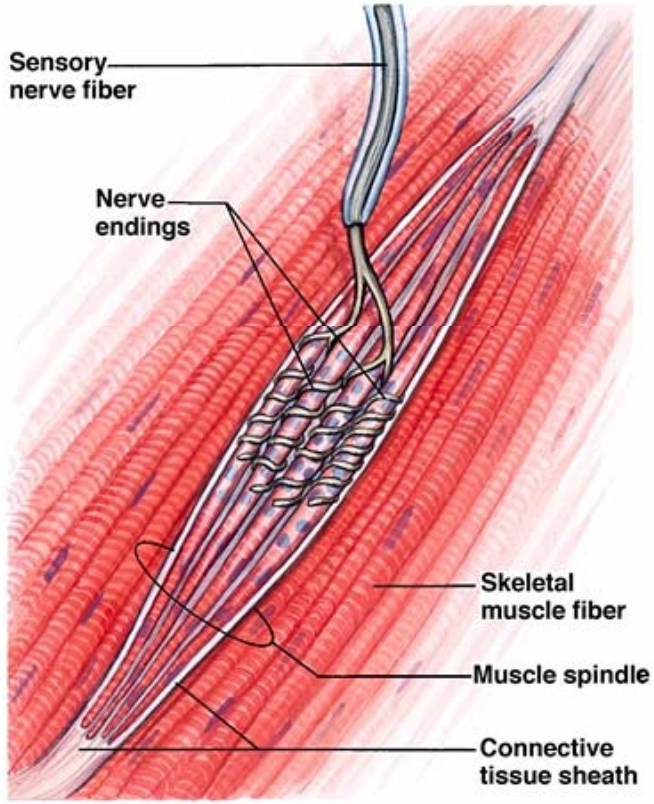
Interstitial fluid

A few thin muscular fibers with many nucleus

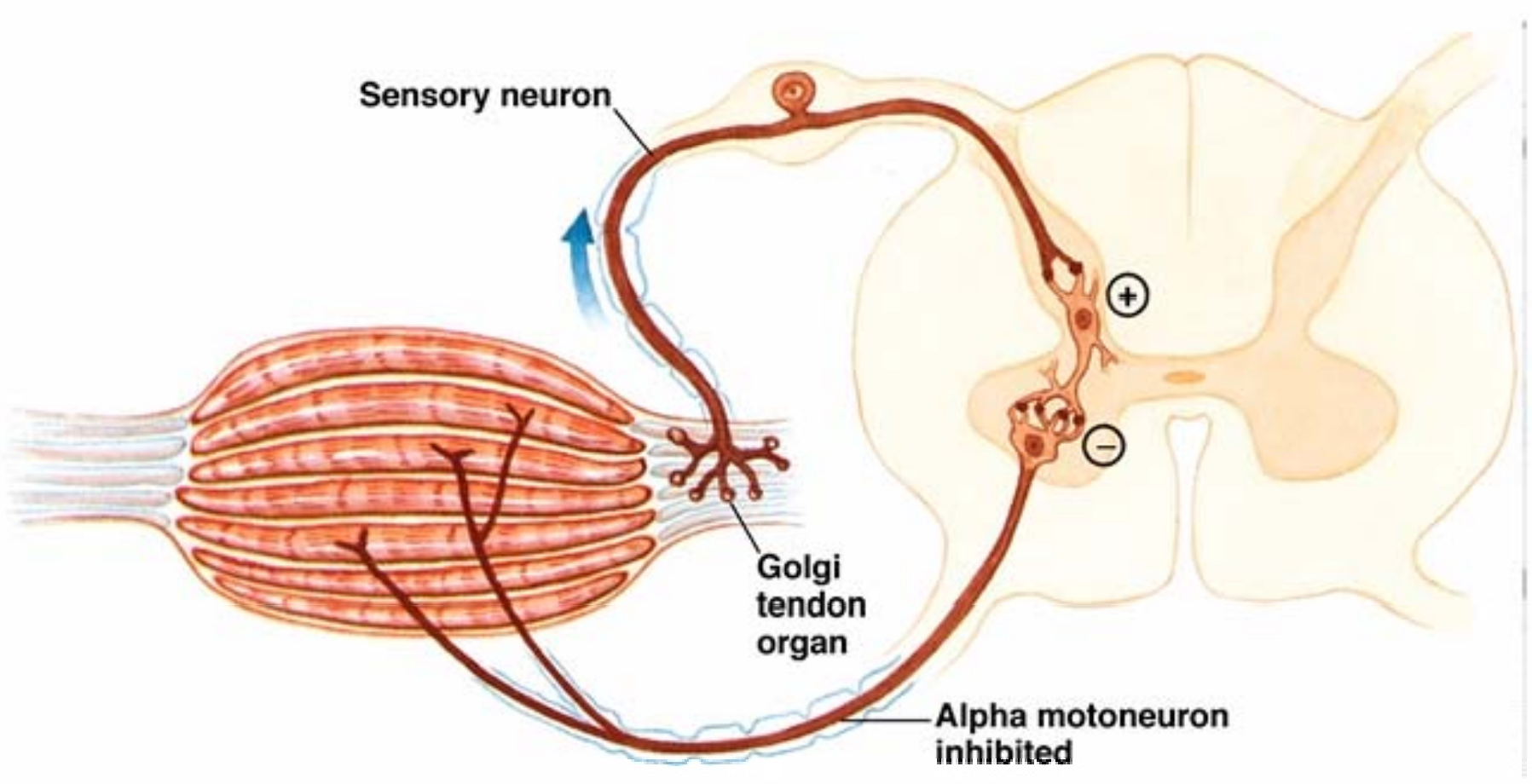
Intrafusal fibers

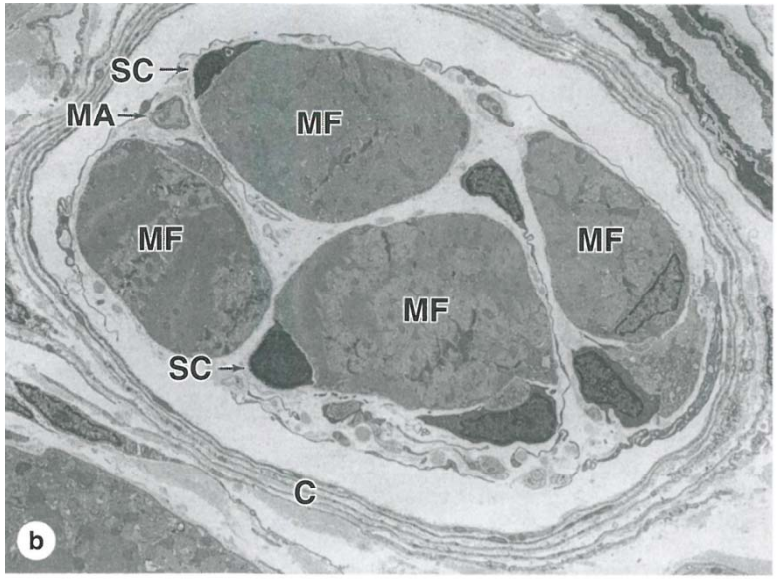



Nuclear bag fiber
External capsule
Group II sensory fibers
Nuclear chain fiber
Static γ motor neuron
Primary ending of group Ia afferent fiber
Nuclei
Internal capsule
α motor fiber
Subcapsular space
Extrafusal fiber
A


Sensory nerve fiber
Nerve endings
Skeletal muscle fiber
Muscle spindle
Connective tissue sheath

Golgi Tendon Organ





(a) The diagram shows both a **muscle spindle** and a **tendon organ**. Muscle spindles have **afferent sensory** and efferent motor nerve fibers associated with the **intrafusal fibers**, which are modified muscle fibers. The size of the spindle is exaggerated relative to the extrafusal fibers to show better the nuclei packed in the intrafusal fibers. Both types of sensory receptors provide the CNS with information concerning degrees of stretch and tension within the musculoskeletal system.

(b) A TEM cross section near the end of a muscle spindle shows the capsule (**C**), lightly myelinated axons (**MA**) of a sensory nerve, and the intrafusal muscle fibers (**MF**). These thin fibers differ from the ordinary skeletal muscle fibers in having very few myofibrils. Their many nuclei can either be closely aligned (nuclear chain fibers) or piled in a central dilation (nuclear bag fibers). Muscle satellite cells (**SC**) are also present within the external lamina of the intrafusal fibers. X3600.

MEDICAL APPLICATION

Dystrophin is a large actin-binding protein located just inside the sarcolemma of skeletal muscle fibers which is involved in the functional organization of myofibrils. Research on **Duchenne muscular dystrophy** revealed that mutations of the dystrophin gene can lead to defective linkages between the cytoskeleton and the extracellular matrix (ECM). Muscle contractions can disrupt these weak linkages, causing the atrophy of muscle fibers typical of this disease.

Muscle fiber types

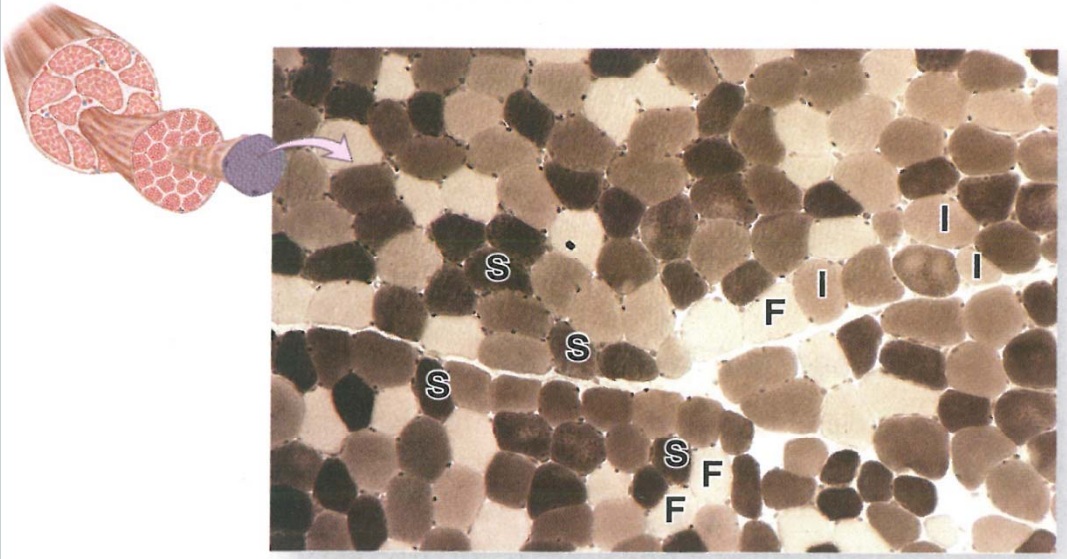
- Brief, episodic & intense contraction
- Mitichondria
- Glycogen

Types

1. Red
2. white
3. Intermediate

Contraction time
Mitochondria
ATP
Capillaries
Myoglobin
Fiber diameter

FIGURE **10–15** Skeletal muscle fiber types.



Cross section of skeletal muscle stained histochemically to detect the density of myofibrillar myosin-ATPase can be used to demonstrate the distribution of slow (**S**) type I fibers, intermediate (**I**) type IIa fibers, and fast (**F**) type IIb fibers. X40. Histochemistry.

Skeletal Muscle

3 Types of Skeletal Muscle Fibers

- Red fibers: high myoglobin, many mitochondria, slow contraction, oxidative metabolism, mammal limbs, migrating bird flight muscle, low glycogen
- White fibers: low myoglobin, fewer mitochondria, breast muscle of chicken and turkey, rapid contraction, low endurance, anaerobic, high glycogen
- Intermediate fibers: properties are between extremes of red and white

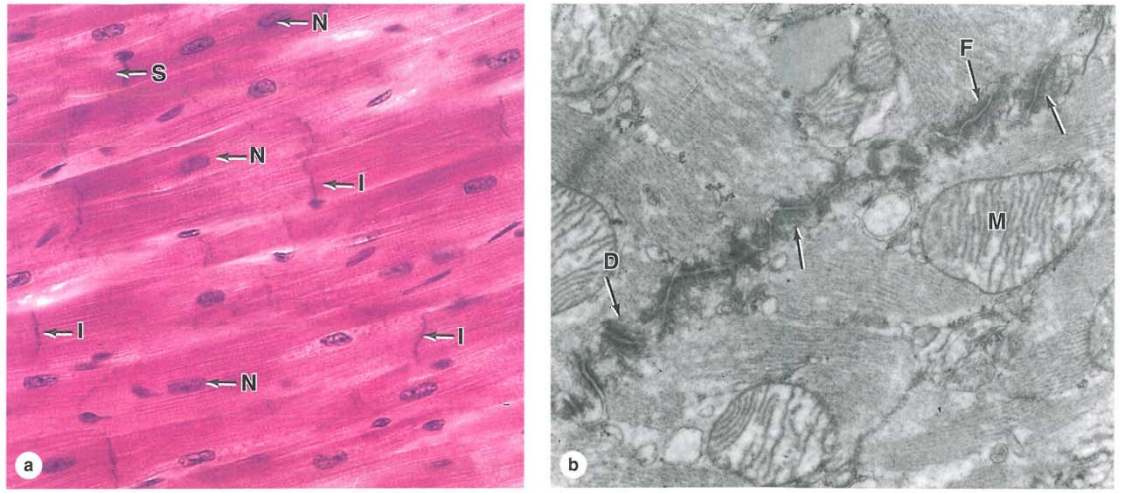
TABLE 10–2 Major characteristics of skeletal muscle fiber types.

	Slow, Oxidative Fibers (Type I)	Fast, Oxidative-Glycolytic Fibers (Type IIa)	Fast, Glycolytic Fibers (Type IIb)
Mitochondria	Numerous	Numerous	Sparse
Capillaries	Numerous	Numerous	Sparse
Fiber diameter	Small	Intermediate	Large
Size of motor unit	Small	Intermediate	Large
Myoglobin content	High (red fibers)	High (red fibers)	Low (white fibers)
Glycogen content	Low	Intermediate	High
Major source of ATP	Oxidative phosphorylation	Oxidative phosphorylation	Anaerobic glycolysis
Glycolytic enzyme activity	Low	Intermediate	High
Rate of fatigue	Slow	Intermediate	Fast
Myosin-ATPase activity	Low	High	High
Speed of contraction	Slow	Fast	Fast
Typical major locations	Postural muscles of back	Major muscles of legs	Extraocular muscles

Cardiac muscle

- Mesodermal cells of primitive heart tube
- Align into chainlike arrays
- Forming complex junctions in interdigitis process
- Interwoven cells

FIGURE **10–17** **Cardiac muscle and intercalated discs.**



(a) Longitudinal sections of cardiac muscle at the light microscope level show nuclei (**N**) in the center of the muscle fibers and widely spaced intercalated discs (**I**) that cross the fibers. The occasional intercalated discs should not be confused with the repetitive, much more closely spaced striations (**S**), which are similar to those of skeletal muscle but less well-organized. Nuclei of fibroblasts in endomysium are also present. X200. H&E.

(b) TEM of an intercalated disc (arrows) shows a steplike structure representing the short interdigitating processes of the adjacent muscle cells (see Figure 10-16). Transverse regions of the disc have many desmosomes (**D**) and adherent junctions called **fascia adherentes (F)**, similar to the macula adherentes of epithelial cells. Less electron-dense regions of the disc have abundant gap junctions. The sarcoplasm has numerous mitochondria (**M**) and myofibrillar structures similar to those of skeletal muscle but slightly less organized. X31,000.

Cardiac cells

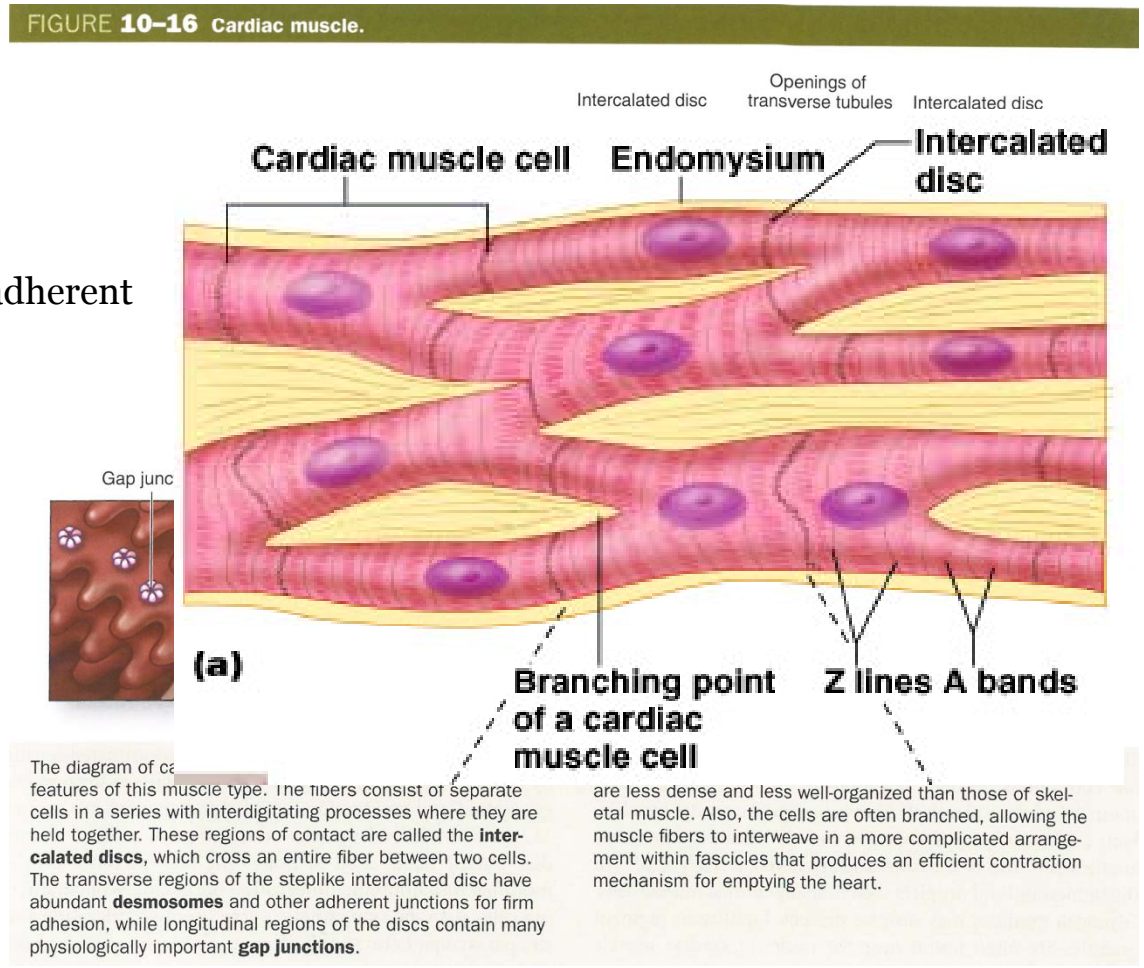
- Cross-striated
- 15μ diameter & 85-100μ length
- 1 or 2 central pale nuclei
- Rich capillary network endomysium
- Intercalated disc

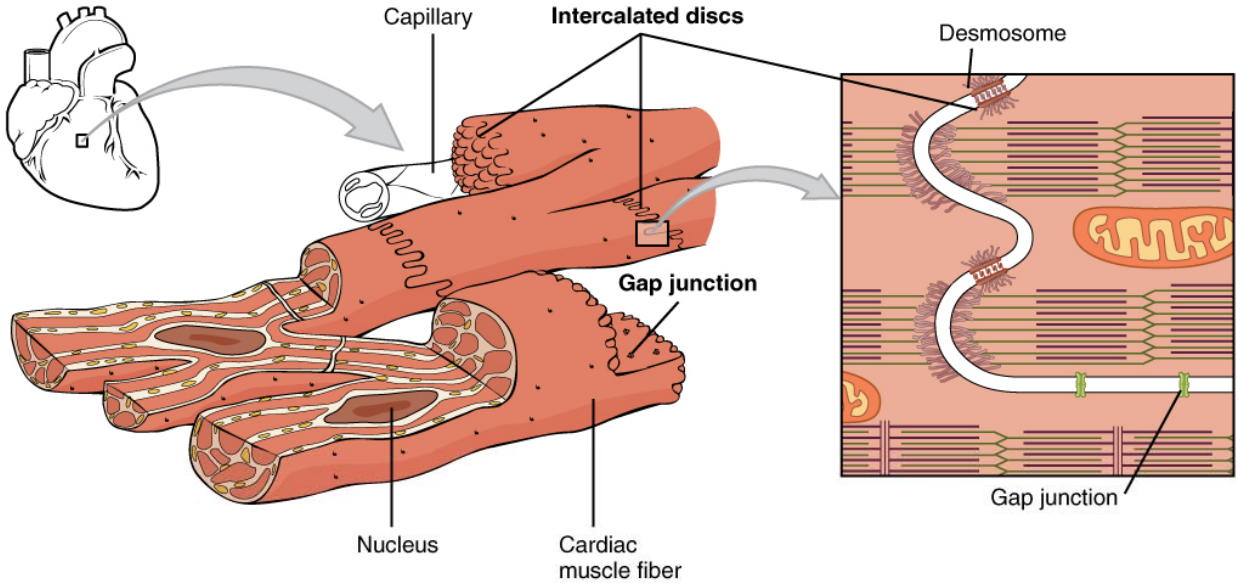
Transverse region: desmosome & fascia adherent
Longitudinal region: gap junction

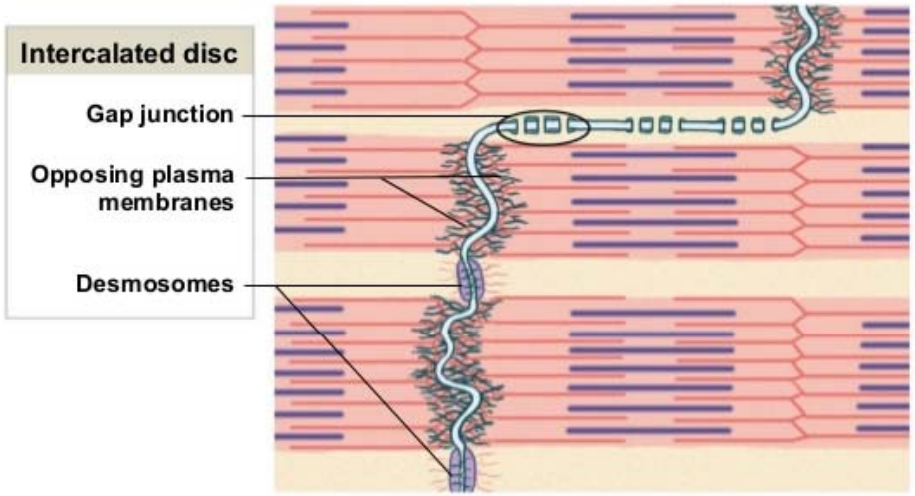
T tubule: more and large
SER: less developed
Mitochondria: 40% of cell

Fatty acid (triglycerid)
Lipofuscin granules near the nucleus

Atrial natriuretic factor (ANF)

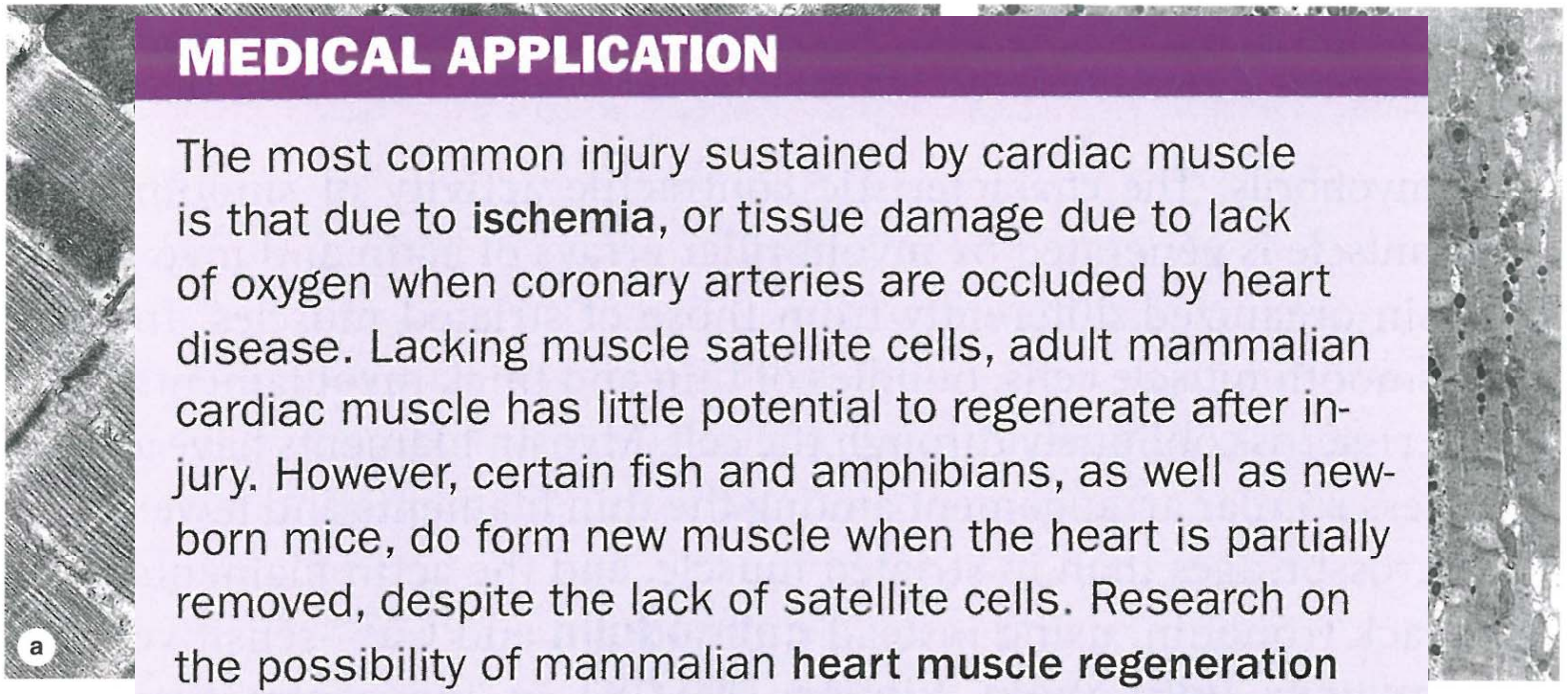






b Structure of an intercalated disc

FIGURE **10–18** **Cardiac muscle ultrastructure.**



MEDICAL APPLICATION

The most common injury sustained by cardiac muscle is that due to **ischemia**, or tissue damage due to lack of oxygen when coronary arteries are occluded by heart disease. Lacking muscle satellite cells, adult mammalian cardiac muscle has little potential to regenerate after injury. However, certain fish and amphibians, as well as newborn mice, do form new muscle when the heart is partially removed, despite the lack of satellite cells. Research on the possibility of mammalian **heart muscle regeneration** builds on work with the animal models, focusing primarily on the potential of mesenchymal stem cells to form new, site-specific muscle.

(a) TEM of
and rather
between m
usually ass
forming dy
Functionally, these structures are similar in these two muscle types. X30,000.

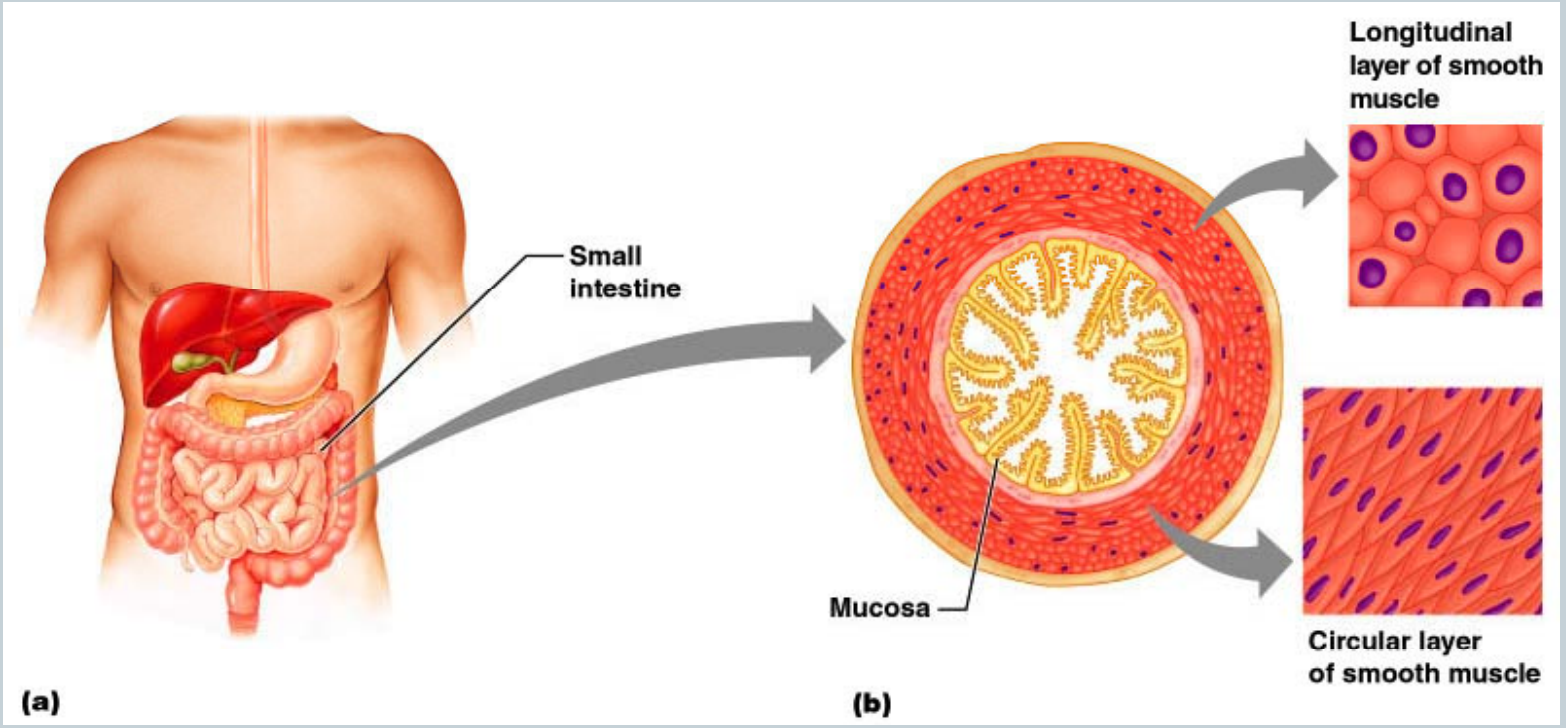
(b) Muscle cells from the heart atrium show the presence of membrane-bound granules (**G**), mainly aggregated at the nuclear poles. These granules are most abundant in muscle cells of the right atrium (~600 per cell), but smaller quantities

he atrial
none,
he kidneys
d diure-
sterone
and antidiuretic hormone, whose effects on kidneys result in sodium and water conservation. X10,000.

(*Figure 10–18b, with permission, from Dr J. C. Nogueira, Department of Morphology, Federal University of Minas Gerais, Belo Horizonte, Brazil.*)

Smooth Muscle

- Grouped into sheets in walls of hollow organs
  - Longitudinal layer – muscle fibers run parallel to organ's long axis
  - Circular layer – muscle fibers run around circumference of the organ
    - Both layers participate in peristalsis



Smooth (visceral) muscle

- Slow steady contraction
- Involuntary
- Longitudinal, tapered & unstriated cells
- Covered by endomysium

thin reticular lamina

Fine network of reticular fibers

Peristaltic

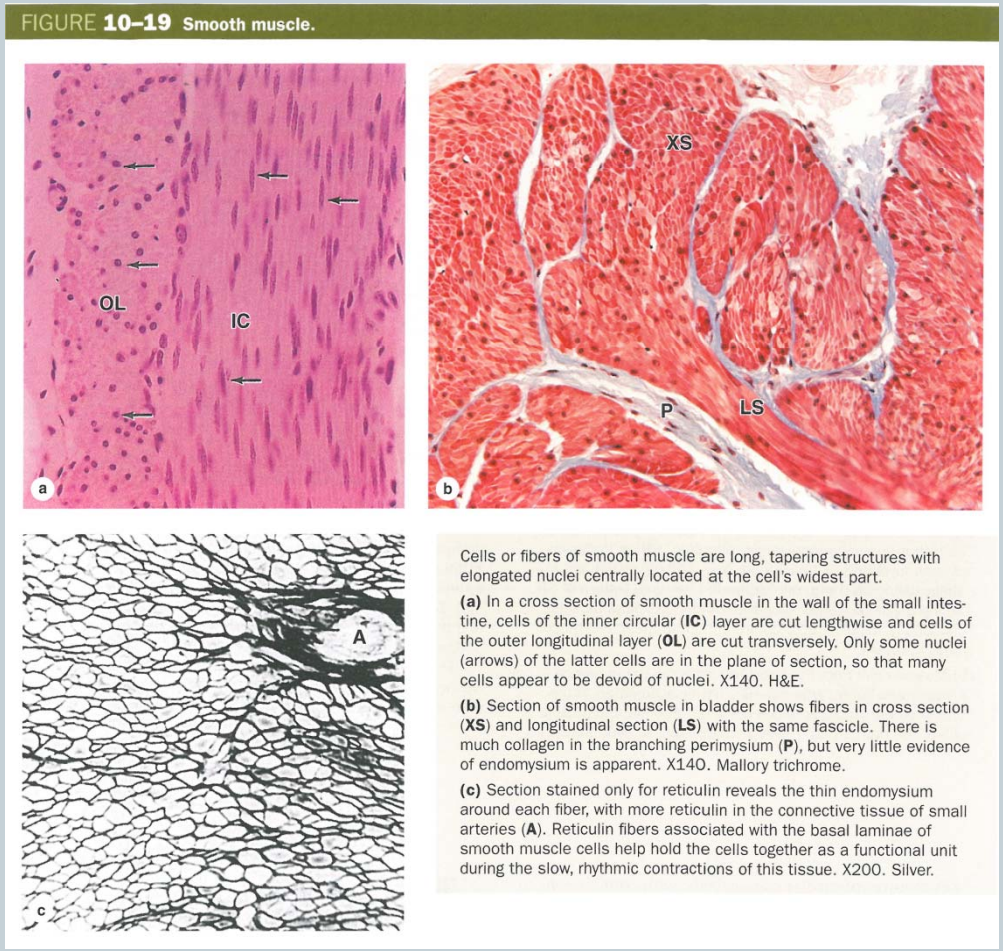
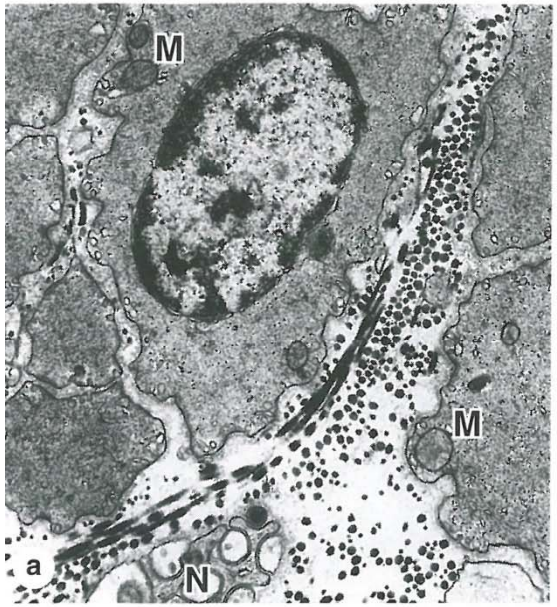
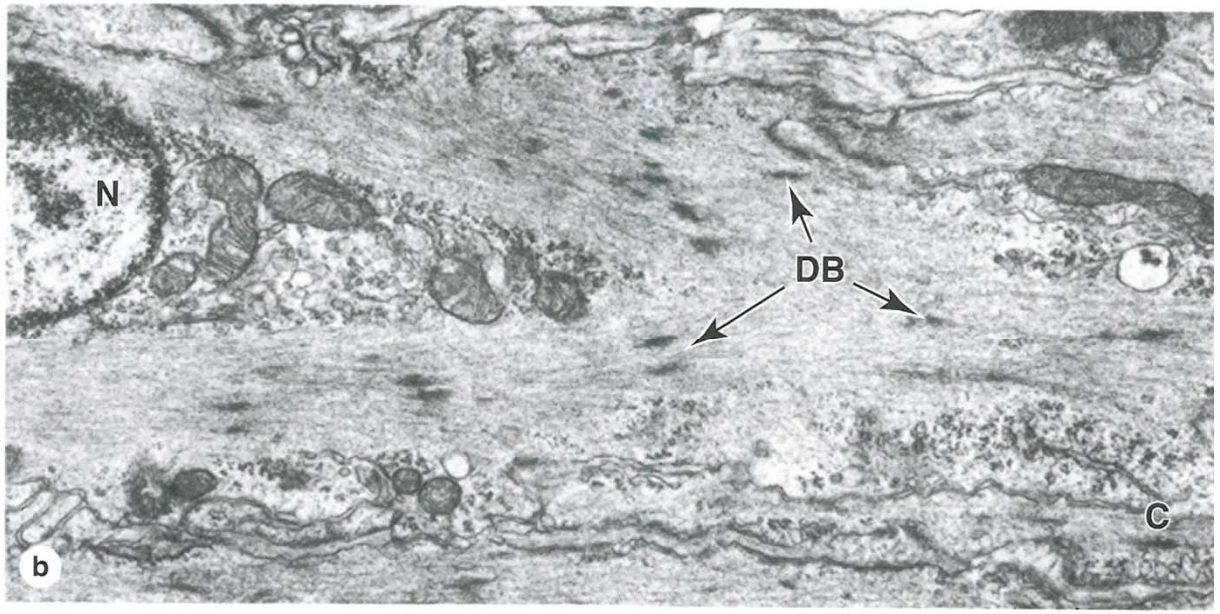


FIGURE 10–20 Smooth muscle ultrastructure.





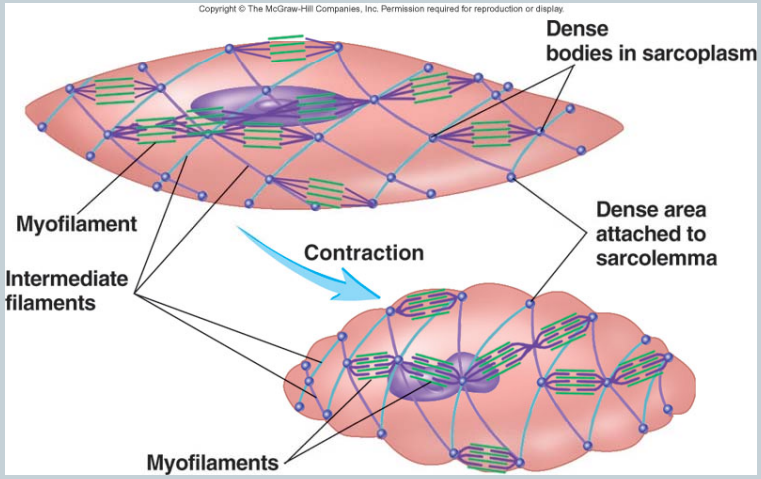
(a) TEM of a transverse section of smooth muscle showing several cells sectioned at various points along their lengths, yielding profiles of various diameters with only the largest containing a nucleus. Thick and thin filaments are not organized into myofibril bundles, and there are few mitochondria (**M**). There is evidence of a sparse external lamina around each cell, and reticular fibers are abundant in the ECM. A small unmyelinated nerve (**N**) is also seen between the cells. X6650.

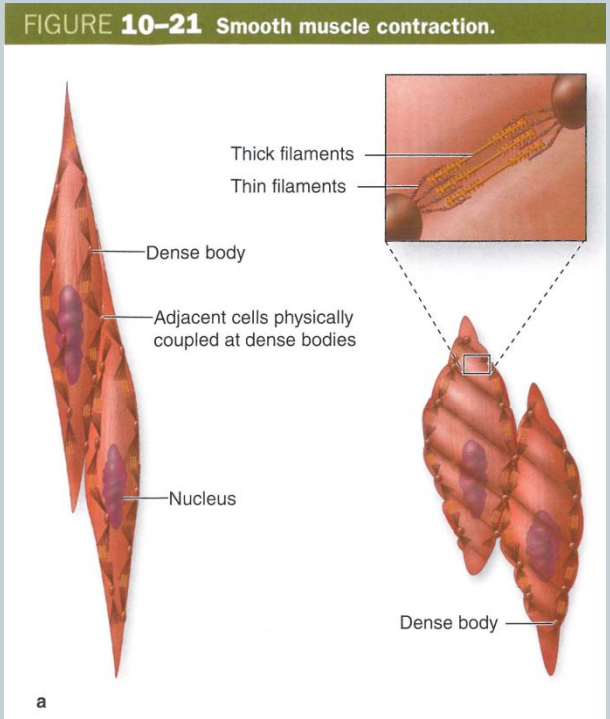
(b) Longitudinal section showing several dense bodies (**DB**) in the cytoplasm and at the cell membrane. Thin filaments and intermediate filaments both attach to the dense bodies. In the cytoplasm near the nucleus (**N**) are mitochondria, glycogen granules, and Golgi complexes. In the lower right corner of the photo the cell membrane shows invaginations called caveolae **(C)** that may regulate release of Ca^{2+} from sarcoplasmic reticulum. X9000.

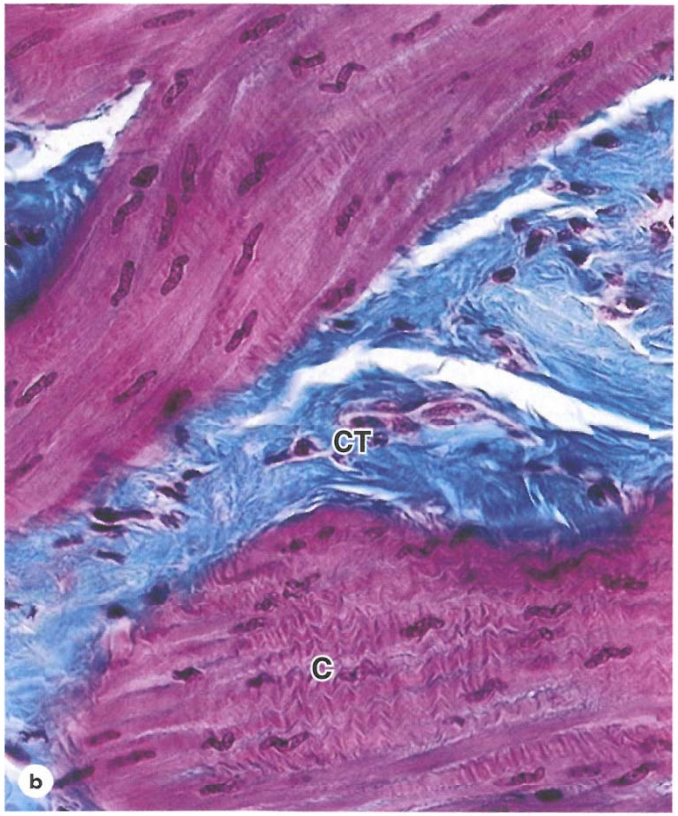
Smooth muscle cells

20-500 µ

- Single long nucleus in center
- Primitive sarcoplasmic reticulum
- Numerous gap junctions
- Caveolae (short membrane invagination)
- Calmodulin (instead troponin)
- Myosin light-chain kinase
- Desmin
- Desmin & actin connected to dense body that contains α actinin
- Dense body Instead Z disc
- ECM synthesis
- Involuntary







apparatus allows the multicellular tissue to contract as a unit, providing better efficiency and force.

(b) Micrograph showing a contracted (**C**) region of smooth muscle, with contraction decreasing the cell length and deforming the nuclei. The long nuclei of individual fibers assume a cork-screw shape when the fibers contract, reflecting the reduced cell length at contraction. Connective tissue (**CT**) of the perimysium outside the muscle fascicle is stained blue. X240. Mallory trichrome.

MEDICAL APPLICATION

Benign tumors called **leiomyomas** commonly develop from smooth muscle fibers but are seldom problematic. They most frequently occur in the wall of the uterus, where they are more commonly called **fibroids** and where they can become sufficiently large to produce painful pressure and unexpected bleeding.

- Cells are not striated

- Fibers smaller than those in skeletal muscle
- Spindle-shaped; single, central nucleus
- More actin than myosin
- No sarcomeres

  - Not arranged as symmetrically as in skeletal muscle, thus NO striations.
- Caveolae: indentations in sarcolemma;
  - May act like T tubules

- Dense bodies instead of Z disks

  - Have noncontractile intermediate filaments
  - **Is innervated by autonomic nervous system**

Muscle tissue regeneration

- **Skeletal muscle**
- Mesenchymal satellite cells in external lamina
- Cell hypertrophy

- **Cardiac muscle**
- No satellite cell
- Fibroblasts

- **Smooth muscle**
- Mitosis in damaged cell
- pericytes