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Muscle Tissue

Matthew Velkey, Ph.D.
Muscle Tissue

I. Striated Muscle - regularly arranged contractile units
   A. Skeletal Muscle - long, cylindrical multinucleated cells with peripherally placed nuclei. Contraction is typically quick and vigorous and under voluntary control. Used for locomotion, mastication, and phonation.

   B. Cardiac Muscle - elongated, branched cells with a single centrally placed nucleus and intercalated discs at the ends. Contraction is involuntary, vigorous, and rhythmic.

II. Smooth Muscle - possesses contractile machinery, but it is irregularly arranged (thus, non-striated). Cells are fusiform with a central nucleus. Contraction is involuntary, slow, and long lasting.
Epimysium - dense irr. c.t.

Perimysium - less dense irr. c.t.

Endomysium - basal lamina and reticular fibers

ALL MUSCLE CELLS HAVE BASAL LAMINAE!
Skeletal Muscle as seen in longitudinal section in the light microscope...

- Multi-nucleated and striated
- A bands - anisotropic (birefringent in polarized light)
- I bands - isotropic (do not alter polarized light)
- Z lines (Zwischenscheiben, Ger. “between the discs”)
- H zone (hell, Ger. “clear”)

Gartner and Hiatt. *Color Atlas of Histology*. Figure 1.
Skeletal Muscle as seen in transverse section in the light microscope...
Organization of Skeletal Muscle Fibers
THE SARCOMERE...

Contractile unit of striated muscle

- Structures between Z lines
  - 2 halves of I bands
  - A band
  - H zone
  - M line (Mittelscheibe, Ger. “middle of the disc”)
- Myofilaments
  - Actin
  - Myosin
- Other structural proteins
  - Titin (myosin-associated)
  - Nebulin (actin-associated)
  - Myomesin (at M line)
  - \( \alpha \) actinin (at Z line)
  - Desmin (Z line)
  - Vimentin (Z line)
  - Dystrophin (cell membrane)
Transverse Section of Skeletal Muscle: TEM view

- **H zone**: thick filaments only
  - At M-line: thick filaments and myomesin lattice
- **A band**: thick & thin filaments
- **I Band**: thin filaments only

Figure 10-12 from Junquiera.
I Band - Actin only
A Band - Actin and Myosin
H Zone - Myosin only
S.R./T-tubule “triad” (⊃)

Longitudinal Section of Skeletal Muscle as observed in the TEM

mitochondria
Sarcoplasmic reticulum
T-tubule
Sarc. ret.

Junquiera. Figure 10-16.
T-tubule System: Propagation of the Signal and Release of Ca\(^{2+}\)

T (transverse) Tubules
- run perpendicular (transversely) to myofibrils
- conduct membrane depolarization deep into fibers

Sarcoplasmic Reticulum
- smooth ER
- site of Ca\(^{2+}\) storage & release
- terminal cisternae abut T-tubules forming triads when myofibrils are viewed in longitudinal section
Longitudinal section of muscle showing triads
• 1 T tubule
• 2 terminal cisternae of sarcoplasmic reticulum
• Normally at A/I junctions in mammals (this sample is from an amphibian)
Neuromuscular Junction

Synapse:
• Action potential (AP) stimulates release of acetylcholine from axon terminal into synaptic cleft
• Acetylcholine in synaptic cleft binds Na\(^+\) channel receptors –initiates sarcolemma AP

Signal Propagation:
T (transverse) Tubules
• Run perpendicular (transversely) to myofibrils
• Conduct membrane depolarization deep into fibers

Intracellular Ca\(^{2+}\) release:
Sarcoplasmic Reticulum
• Smooth ER, site of Ca\(^{2+}\) storage
• Voltage-gated channels in SR detect membrane depolarization in T-tubule and release Ca\(^{2+}\)
Muscle Innervation: Motor End Plate

1. presynaptic terminal
2. sarcolemma
3. synaptic vesicles
4. Acetylcholine receptors
5. mitochondrion
Ca^{2+} Stimulates Myosin-Actin Binding and Initiates Contraction

- Myosin-actin binding inhibited by TnI
- TnC binds Ca^{2+} (if present) and induces release of TnI from actin
- Myosin binds actin; hydrolysis of ATP induces power stroke
- Actin filaments move relative to myosin
1. ATP binds myosin – myosin releases actin
2. ATP hydrolysis induces conformational change – myosin head cocks forward 5nm (ADP+P_i remain bound to myosin).
3. Myosin binds weakly to actin, causing release of P_i
4. Release of P_i induces strong binding, power stroke, and release of ADP

Myosin remains bound to actin if no more ATP is available (rigor conformation)
Muscle fibers are composed of many contractile units (sarcomeres)

Changes in the amount of overlap between thick and thin filaments allows for contraction and relaxation of muscle fibers

Many fibers contracting together result in gross movement

**Note:** Z lines move closer together; I band and H band become smaller during contraction
Cardiac Muscle

Tissue Features:
• Striated (same contractile machinery)
• Self-excitatory and electrically coupled
• Rate of contractions modulated by autonomic nervous system
  – Innervation is neuroendocrine in nature (i.e. no “motor end plates”)

Cell Features:
• 1 or 2 centrally placed nuclei
• Branched fibers with intercalated discs
• Numerous mitochondria (up to 40% of cell volume)
• Sarcoplasmic reticulum & T-tubules appear as diads at Z lines
  – Sarcoplasmic reticulum does not form terminal cisternae
  – T tubules are about 2x larger in diameter than in skeletal muscle
    • Transport Ca^{2+} into fibers
Cardiac Muscle (longitudinal section)

- Intercalated disk
- Glycogen & secretory granules

Source Undetermined
Cardiac Muscle (longitudinal section)  Cardiac Muscle (transverse section)

Gartner and Hiatt. *Color Atlas of Histology*. Figure 2 and Figure 4 from Plate 6.8
Transverse Section of Cardiac Muscle versus Skeletal Muscle
Cardiac Muscle (TEM)

T Tubule/SR Diads

Left from Junquiera. Figure 10-24.
Right: Source Undetermined
Intercalated Discs Couple Heart Muscle Mechanically and Electrically
Transverse portion: forms mechanical coupling

Lateral Portion: forms electrical coupling

aka “Fascia adherens”

Source Undetermined

Smooth Muscle

- Fusiform, non-striated cells
- Single, centrally-placed nucleus
- Contraction is non-voluntary
- Contraction is modulated in a neuroendocrine manner
- Found in blood vessels, GI and urogenital organ walls, dermis of skin
Smooth Muscle (longitudinal section)
Smooth Muscle Viewed in Transverse and Longitudinal Section

Junquiera. Figure 10-30.

Color Atlas by Gartner and Hiatt. Figure 4 from plate 6.6.
Ultrastructure of Smooth Muscle:

- actin and myosin filaments
- intermediate filaments of desmin (also vimentin in vascular smooth muscle)
- membrane associated and cytoplasmic dense bodies containing \( \alpha \) actinin (similar to Z lines)
- relatively active nucleus (smooth muscle cells make collagen, elastin, and proteoglycans)
Smooth Muscle Viewed in Cross Section (TEM)

What is the structure marked by *?

Also, note collagen – SMC secrete ECM: collagen (I,III, IV), elastin, and proteoglycans
More Ultrastructure of Smooth Muscle Cells:

- microtubules (curved arrows)
- actin filament (arrowheads)
- intermediate filaments
- dense bodies (desmin/vimentin plaques)
- caveoli (membrane invaginations & vesicular system contiguous with SER – functionally analogous to sarcoplasmic reticulum)

Cross and Mercer. Inset of plate 114.
Smooth Muscle Contraction:
also Ca+ dependent, but mechanism is different than striated muscle
1. Ca2+ ions released from caveloae/SER and complex with calmodulin
2. Ca2+-calmodulin activates myosin light chain kinase
3. MLCK phosphorylates myosin light chain
4. Myosin unfolds & binds actin; ATP-dependent contraction cycle ensues.
5. Contraction continues as long as myosin is phosphorylated.
6. “Latch” state: myosin head attached to actin dephosphorylated causing decrease in ATPase activity –myosin head unable to detach from actin (similar to “rigor mortis” in skeletal muscle).

Triggered by:
• Voltage-gated Ca+ channels
  activated by depolarization
    • Mechanical stimuli
    • Neural stimulation
• Ligand-gated Ca+ channels

Ross and Pawlina. Figure 11.23.
Mechanics of Smooth Muscle Contraction

- Dense bodies are analogous to Z lines (plaques into which actin filaments insert)
- Myosin heads oriented in “side polar” arrangement
- Contraction pulls dense bodies together

Additional notes:
- Contraction cycle generally about ~10% as fast as skeletal muscle
- Visceral (unitary) smooth muscle cells may be electrically coupled via gap junctions and exhibit either rhythmic or tonic contraction—innervation generally modifies smooth muscle activity rather than initiating it.
- Multunit smooth muscle cells are innervated individually and can contract rapidly for more precise control.
- Innervation is always at a distance (no motor end plates)
Smooth Muscle (vascular)

Relaxed

Contracted
Smooth Muscle VERSUS Nerve VERSUS Connective Tissue
Slide 250 vagina

Epithelium

B.V.

CT

SM

Nerve

SM

U-M Histology Collection slide 250.
Muscle types

Skeletal muscle

Cardiac muscle

Smooth muscle

Activity

Cross sections

Strong, quick discontinuous voluntary contraction

10-100µm in diameter
Up to 30cm in length

Strong, quick continuous involuntary contraction

10-15µm in diameter
80-100µm in length

Weak, slow involuntary contraction

0.2-2µm in diameter
20-200µm in length
Muscle Regeneration and Growth

Skeletal Muscle
• Increase in size (hypertrophy)
• Increase in number (regeneration/proliferation)
  • Satellite cells are proposed source of regenerative cells

Smooth Muscle
• Increase in size (hypertrophy)
• Increase in number (regeneration/proliferation)
  • Smooth muscle cells are proliferative
  (e.g. uterine myometrium and vascular smooth muscle)
  • Vascular pericytes can also provide source of smooth muscle

Heart Muscle
• Increase in size (hypertrophy)
• Formerly thought to be non-proliferative
  • Post-infarction tissue remodeling by fibroblasts (fibrosis/scarring)
  • New evidence suggests mitotic cardiomyocytes and regeneration
    by blood or vascular-derived stem cells
Skeletal Muscle Satellite Cell
Activated satellite cell in skeletal muscle
Learning Objectives

1. Be able to identify the three types of muscle at the light and electron microscope levels, including distinctive features of each, such as the intercalated disk of cardiac muscle.

2. Be able to describe the structural basis of muscle striation.

3. Know the structural elements that harness muscle contraction (i.e., the shortening of myofibrils) to the movement of a body part (i.e., via connection to bone) as well as the mechanism by which muscle cells contract.

4. Understand the function and organization of the connective tissue in muscle (endo-, peri-, and epiysium).

5. Be familiar with the regenerative potential of each muscle type.
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Slide 17: Source Undetermined
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Slide 33: Source Undetermined
Slide 34: Source Undetermined
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