Skeletal Muscle : Structure

Dr.Viral I. Champaneri, MD
Assistant Professor
Department of Physiology

Learning objectives

1. Gross anatomy of the skeletal muscle
2. Myofilaments & their molecular structure
    1. Myosin (Thick)
    2. Actin (Thin)
3. Sarcomere

Short notes (4 marks)

1. Sliding filament cross bridge cycling (3)
2. Sliding filament mechanism of skeletal muscle contraction
3. Sarcomere
4. Cross bridge cycling in a skeletal muscle fiber

Labeled diagram

1. Sarcomere

Muscles in the body

- **40% of the body is skeletal muscle**
- **10% Smooth muscle & Cardiac muscle**

Skeletal Muscle: Physiological Anatomy

- Composed of individual muscle fiber
- Building blocks of the muscular system
- Neurons: building blocks of the nervous system

Skeletal Muscle: Physiological Anatomy

- **Most of the Skeletal muscle**
- **Begin**
- **End**
- **In tendons**

Skeletal Muscle: Physiological Anatomy

- Composed of numerous fibers
- 10 to 80 micrometer in diameter
- Each fiber in turn made up of smaller subunits
- Myofibrils

Skeletal Muscle :Physiological Anatomy

- **Muscle fibers**
- **Arranged in parallel between**
- **Tendinous end**
- **Force of contraction of unit is additive**

Sarcolemma

- Cell membrane of the muscle fiber
- Consists of true cell membrane
- Called Plasma membrane

Sarcolemma → Outer coat

- Made up of a thin layer of
- Polysaccharide material
- Contain thin collagen fibrils

Epimysium *(epi = above)*

- **The fibrous connective tissue proteins**
- **Within the tendons extend**
- **Around the muscle in an irregular arrangement**
- **Forming a sheath known as**
- **The *epimysium (Epi = above; My = muscle)***

Perimysium

- **From this outer sheath (Epimysium)**
- **Connective tissue**
- **Extends into the body of the muscle**
- **Subdividing it into *columns*, or *fascicles***

Perimysium *(peri = around)*

- **Each of these fascicles is**
- **Surrounded by its own connective tissue sheath**
- **known as the *perimysium (peri = around).***

Endomysium

- **Sarcolemma (Plasma membrane) of muscle fiber**
- **Enveloped by a thin connective tissue**
- **Layer called an *endomysium***

Tendon

- At each end of the muscle fiber
- Surface layer of the sarcolemma
- Fuses with a tendon fiber
- Tendon fibers collect in to bundles ➔form Tendon
- Insert in to bones

Myofibrils *(fibril = little fiber)*

- **Muscle fiber composed of**
- **Several 100 to 1000**
- **Myofibrils (*fibrils* = little fibers)**

Myofibrils

- Diameter : 1 micrometer (1 μ m)
- Extend in parallel rows
- From one end of the muscle fiber to the other

Myofibrils

- Densely packed
- Organelles restricted
- To the narrow cytoplasmic spaces that
- Remain between adjacent myofibril

Myofilaments

- **Each myofibril**
- **In turn composed of about**
- **1500 : Myosin filaments**
- **3000: Actin filaments**

Myosin & Actin Myofilaments

- **Polymerized protein molecules**
- **Responsible for**
- **Actual muscle contraction**

Myosin & Actin Myofilaments

- **Thick filaments ➔ *Myosin***
- **Thin filaments ➔ *Actin***
- ***Thin ➔ (Ac)Tin***

Myosin (Thick) Myofilaments

- **Form of myosin in muscle: Myosin-II**
- **MW : 4,80,000**
- **Organization of many myosin molecules for myosin filament**

Myosin Myofilaments ➔ Chains

- **6 Polypeptide chains**
- **2 heavy chains with a MW 2,00,000**
- **4 light chains with a MW 20,000**

Myosin Myofilaments➔ Tail

- **2 heavy chains wrap around each other**
- **To form a *double helix***
- **Called ➔ *Tail of myosin***

Myosin Myofilaments➔ Head

- One end of each of heavy chains
- Folded into a globular polypeptide structure
- Called *Myosin head*

Myosin Myofilaments➔ Head

- **Light chains and**
- **Amino terminal portion of heavy chains**

Myosin Myofilaments ➔ 4 Heads

- 4 heads ➔lying side by side
- At ➔One end of the double helix myosin molecule
- 4 light chains parts of head
- 2 light chains to each head

Myosin Myofilaments:4 Light chains

- **Importance ➔**
- **During muscle contraction**
- **Help to control the function of the head**

Myosin Myofilaments : Body

- Myosin filament made up of
- ≥ 200 myosin molecules
- Tails bundled together to form ➔Body

Myosin Myofilaments : Arm

- **Part of each myosin molecule**
- **Hangs, to the side along with the head**
- **Arm : Extend from head outward from the body**

Myosin Myofilaments: Cross bridges

- **Protruding arms and heads**
- **Together (Arm + Heads)**
- **Called cross-bridges**

Myosin Myofilaments: Hinges

- **Cross-bridge is flexible at 2 points**
- **One: Where arm leaves the body of the myosin filament**
- **Second: Where head attaches to the arm**

Myosin Myofilaments: Hinges

- Hinged arms allows heads
- Either to
- Extend far outward from the body of myosin filament
- To be brought close to the body

Myosin Myofilaments: Hinges

- Hinged arm
- Participate
- Actual contraction of the muscle

Myosin Myofilaments: Length

- **Uniform**
- **1.6 micrometer (µm)**

Myosin Myofilaments: Centre

- No cross-bridge head
- In very centre of the myosin filament
- For distance of 0.2 micrometer (µm)
- Hinged arms extends away from the centre

Myosin Myofilaments: Cross bridges

- Cross bridge pair is axially displaced
- From previous pair by 120 degrees
- Cross bridges extends in all directions
- Around the filament

Myosin Myofilaments➔ Head

- Catalytic site ➔ Function as an
- ATPase enzyme ➔ Hydrolyzes ATP
- Use energy
- Derived from high-energy phosphate bond
- To energize the contraction

Myosin (Thick) Myofilaments:Head

- **Actin-binding site**

Actin (Thin) Myofilaments (F-actin)

- The Actin filament or F-actin 1 µm long
- Polymer formed of
- 300 to 400 globular subunits (G-actin)
- F-actin is backbone of actin filament

Actin Myofilaments (F- actin): G - Actin

- Each strand of double F-actin helix composed of
- G-actin (Globular subunits)
- Polymerized molecules
- MW 42,000
- Each strand of helix → 13 G-actin molecules

Actin (Thin) Myofilaments: Active sites

- Each one of the G-actin molecules
- 1 molecule of ADP attached
- ADP molecules
- Active sites on the actin filaments

Actin (Thin) Myofilaments: Active sites

- **ADP molecules active sites**
- ***Cross bridges of myosin filaments interact***
- **To cause muscle contraction**

Actin (Thin) Myofilaments: Active sites

- Active sites are staggered
- On 2 F-actin strands of the double helix
- 1 active site present every
- 2.7 nanometers (nm)

Actin (Thin) Myofilaments

1. **Tropomyosin : 40-60 molecules**
2. **Actin : 300-400 molecules**
3. **Troponin**

Actin Myofilaments: Tropomyosin

- **MW 70,000**
- **Length 40 nanometer (nm)**
- **Wrapped spirally around sides of the F-actin helix**

Actin Myofilaments: Tropomyosin

- Lies within the groove
- Between
- The double row of G-actin monomers

Actin Myofilaments: Tropomyosin

- 40 to 60 tropomyosin molecules per thin filament
- Each tropomyosin spanning a distance of
- Approximately 7 actin subunits (G-actin)

Actin Myofilaments: Tropomyosin

- **Resting stage ➔ 40 – 60 Tropomyosin molecules**
- **Lie on the top of active sites**
- **ADP molecules on Actin filaments**

Importance of Tropomyosin

- **Attraction can not occur between**
- **Actin (Thin) and myosin (Thick) filaments**
- **To cause contraction during resting stage**

Actin Myofilaments: Troponin

- **Protein molecules**
- **Attached along the side of tropomyosin**
- **Rather than directly to F-actin**

Actin Myofilaments: 3 Troponins

- **Complex of 3 loosely bound protein subunits:**

1. **Troponin I**
2. **Troponin T**
3. **Troponin C**

Actin Myofilaments: Troponin I

- Inhibits the binding of the cross bridges to actin
- Strong affinity for actin (F-actin)

Actin Myofilaments: Troponin T

- **Bind**
- **Troponin components to the Tropomyosin**

Actin Myofilaments: Troponin C

- **Binding sites for Ca^{2+}**
- **Helps to initiate contraction**

Striations

- Difference in refractory index of the various parts
- Of the muscle fiber
- Responsible for
- The characteristic cross –striations seen in skeletal muscle under electron microscope

Striations

- **Myosin and Actin filaments**
- **Partially interdigitate**
- **Cause the myofibril to have**
- **Alternate Light and Dark bands**

Striations

- **The parts of the cross-striation frequently**
- **Identified by**
- **Letters**

Light bands *(I bands)*

- **Contains only Actin filaments (Thin= 50 to 60 Aº)**
- **1 Aº= 10^{-10} m**
- **Called *I bands***
- **Because they are ➔ *isotropic to polarized light***

Dark bands (*A bands*)

- **Contains only Myosin filaments (Thick = 110 Aº)**
- **As well as ends of Actin filaments**
- **Actin filaments overlap the myosin filament**
- **Called *A bands***
- ***Anisotropic to polarized light***

A band : Electron microscope

- **Transverse section through**
- **The A band is examined under the electron microscope**

A band : Electron microscope

- **Each (1) thick (Myosin) filament**
- **Surrounded by six thin (6 Actin) filaments**
- **In regular hexagonal pattern**

A band : Electron microscope

- **Thick (Myosin) and thin (Actin) filaments**
- **Overlap ➔ At the edges of each A band**
- **The edges of the A band are darker in appearance**
- **Than the central region**

H Zone (H → helle → bright)

- **These central lighter regions of the A bands**
- **Are called the *H bands***
- ***for helle, a German word* meaning "bright"**

H Zone (H ➔ helle ➔ bright)

- **Contain only thick (Myosin) filaments**
- **That are not overlapped**
- **By thin (Actin) filaments**

M line ➔ Middle of the H band

- **Seen in the middle of the H band**
- **Produced by protein filaments located at the centre of the thick filaments**
- **(and thus the A band)**

Pseudo-H Zone

- **M Line**
- **Plus**
- **The narrow light areas on either side of M line**
- **Called *pseudo-H Zone***

Cross bridges

- **Small projections from the side of the myosin filaments**
- **Entire extent of the myosin (Thick) filament**
- **Except in very centre (0.2µm)**

Z Disc ➔ End of Actin filament attached

- **End of Actin filaments attached to the ➔ Z disc**
- **From Z disc Actin filaments**
- **Extends in both directions**
- **To interdigitate with myosin filaments**

Z Disc

- **Composed of filamentous proteins**
- **Different from the actin and myosin filaments**
- **Passing crosswise across myofibril**
- **From myofibril to myofibril**

Z Disc ➔ Attaching myofibril

- **To one another**
- **All the way across the muscle fiber**
- **Entire muscle fiber has Light and Dark bands**

Striation

- Entire muscle fiber has Light and Dark bands
- As individual myofibril
- These bands gives skeletal and cardiac muscle
- Striated appearance

Sarcomere (2 µm)

- Portion of the myofibril
- Or whole muscle fiber
- That lies between
- Two successive Z Disc ➔ Sarcomere

Sarcomere (2 µm)

- When muscle fiber is at normal
- Fully stretched
- Resting length of the sarcomere is ➔2 µm