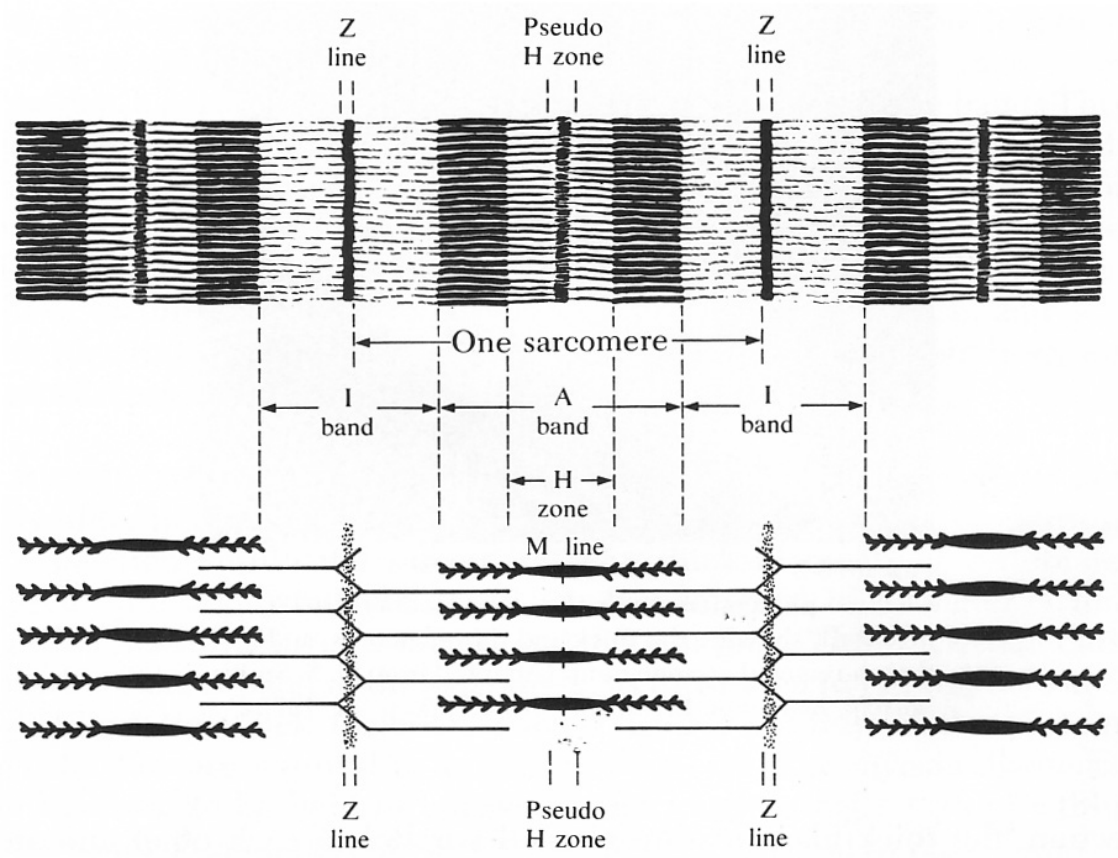
ANSC/FSTC 607
Physiology & Biochemistry of Muscle as a Food
Muscle Ultrastructure



I. Sarcomeres

A. Sarcomeres are the functional units of myofibrils.

B. Resting length is 2-3 μm (from Z-line to Z-line).

II. Myofilaments

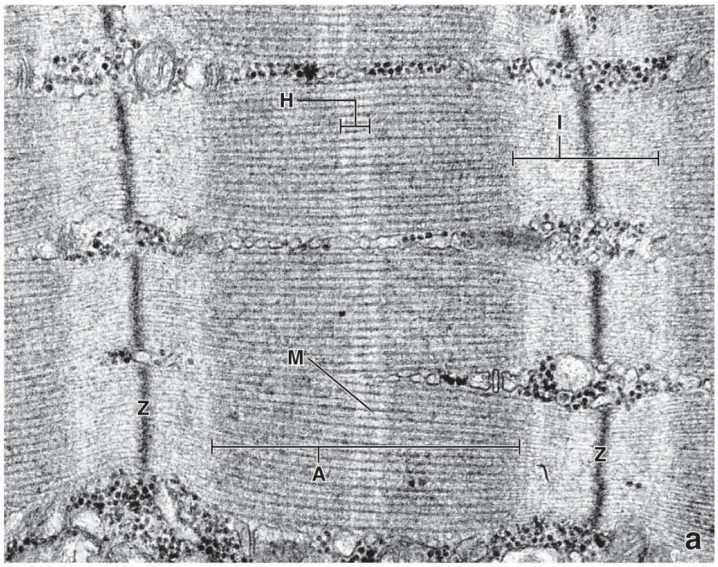
A. Thick filament

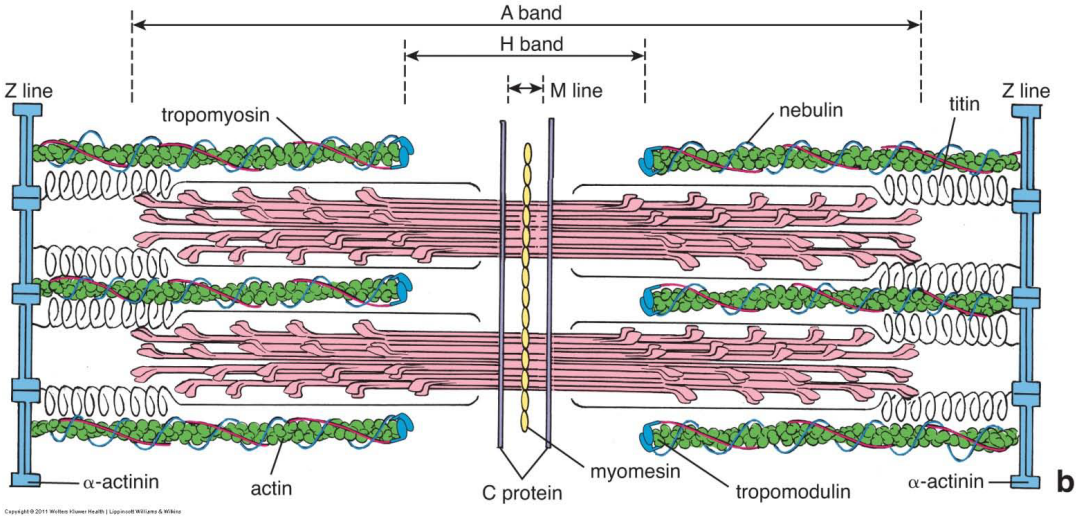
1. Dimensions

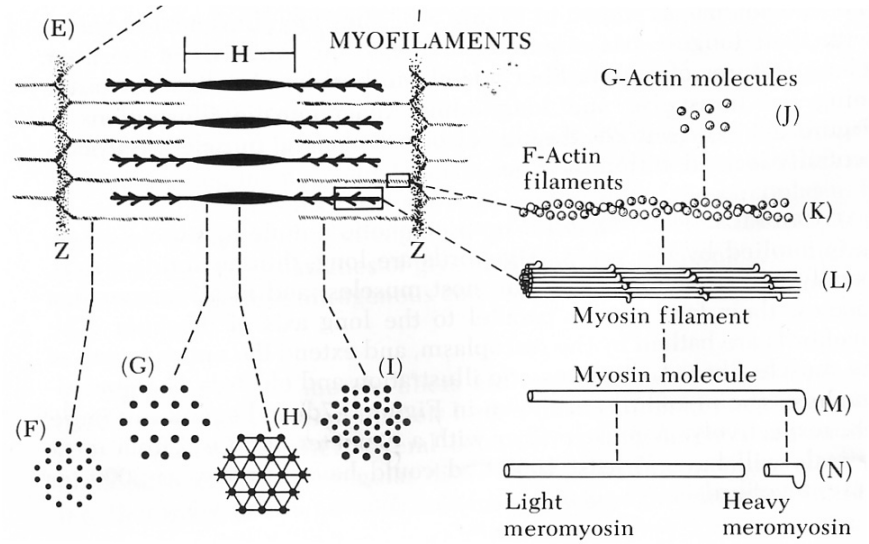
a. Length = 1.0 - 1.6 μm

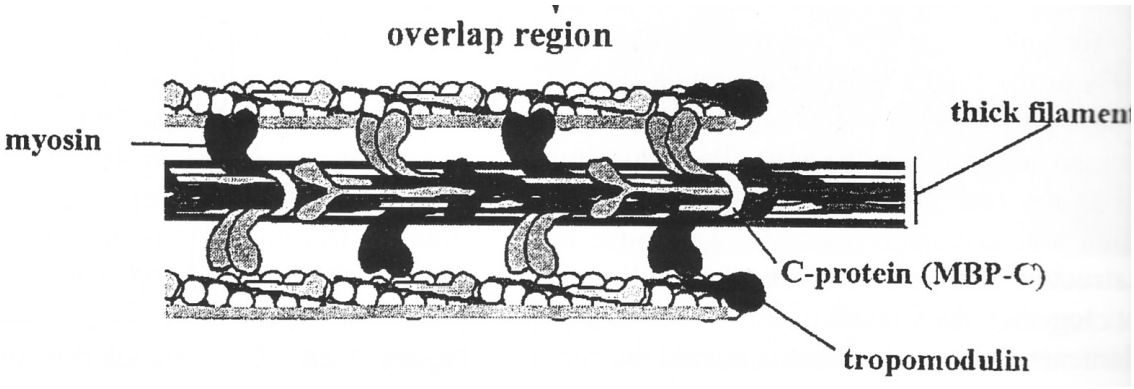
b. Diameter = 10 - 12 nm

c. MW = 160 x 10^6 daltons. Approx. 200 myosin molecules/thick filament


H
I
M
Z
A
Z
a

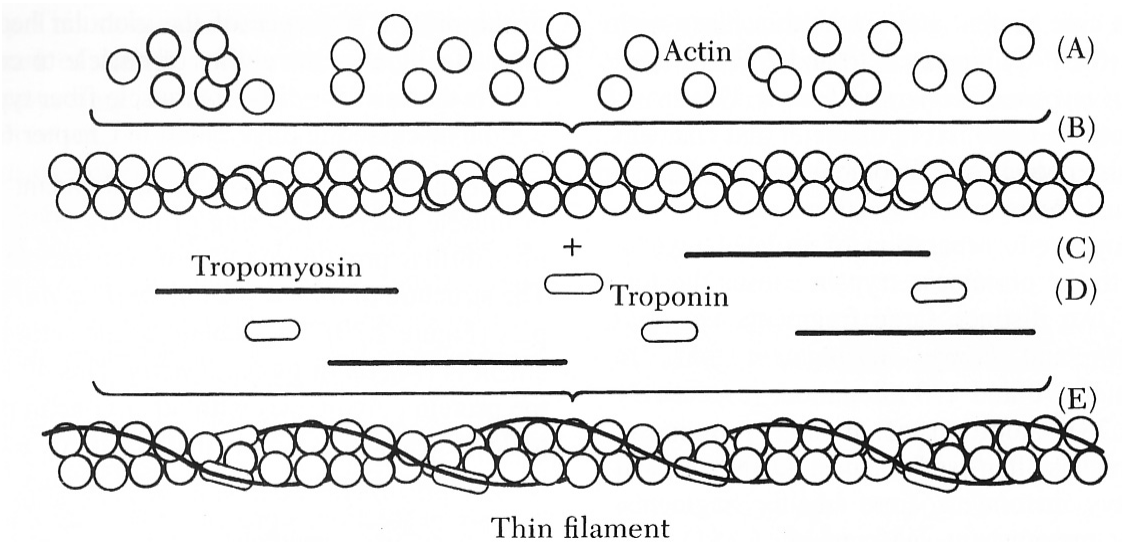

A band
H band
M line
Z line
tropomyosin
nebulin
titin
Z line
α-actinin
actin
C protein
myomesin
tropomodulin
α-actinin
b


(E)
H
MYOFILAMENTS
G-Actin molecules
(J)
F-Actin filaments
(K)
Z
Z
(L)
Myosin filament
Myosin molecule
(M)
(N)
(G)
(I)
(F)
(H)
Light meromyosin
Heavy meromyosin



B. Thin filament

1. Dimensions
   a. Length = 1.0 μm
   b. Diameter = 5 - 7 nm
   c. MW = 10 x 10^6 daltons
2. Configuration
   a. There are 150 - 200 globular (G)-actin molecules per filamentous (F)-actin.
   b. Two F-actins per thin filament.
   c. 13 G-actin molecules per α-helical turn.



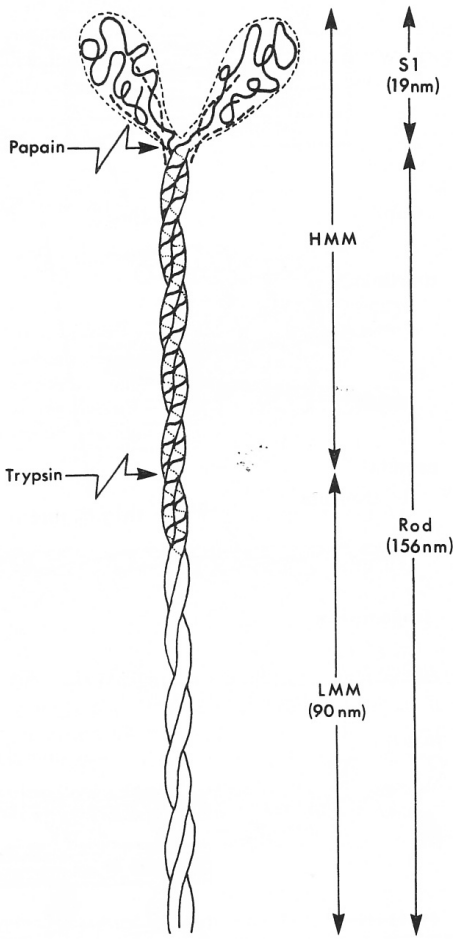
Thin filament

C. Proteolytic fragments of myosin molecule (MW 470 kd) produced with *trypsin.*

1. Light meromyosin
    a. "Tail" only
    b. MW = 140 kD
2. Heavy meromyosin
    a. "Head" plus remainder of "tail"
    b. MW = 340 kD

D. Subfragments produced by cleavage with *papain*.

1. HMM-1 (head only; S1)
2. HMM-2 (tail only)



III. Contractile proteins

A. Myosin heavy chain (MHC; 2/molecule)

1. MW ≈ 200 kD
2. Most abundant: 43% of total myofibrillar protein
3. Myosin light chains (MLC; 4/molecule)
    a. MWs are variable because isoforms exist in fast- and slow-twitch muscles.
    b. MLC-1 MW ≈ 21 kD (alkali light chain)
    c. MLC-3 MW ≈ 17 kD (another alkali light chain)
    d. MLC-2 MW ≈ 18 kD (regulatory light chain)

B. G-actin

1. 22% of total myofibrillar proteins
2. MW ≈ 43 kD
3. Bound by ionic and hydrophobic bonds to form F-actin.
4. Each G-actin has polarity, i.e., can arrange head-to-tail.

IV. Regulatory proteins

A. Tropomyosin

1. 5% of total myofibrillar proteins
2. MW = 71 kD (dimer: Trp_{α} = 33 kD; Trp_{β} = 37 kD)
3. In series: each Trp molecule spans 7 G-actins.
4. One tropomyosin series for each F-actin.

B. Troponins (5% of total myofibrillar proteins)

1. Troponin-I
   a. MW = 21 kD
   b. Known as the inhibitory troponin.
   c. Troponin-I binds to actin to inhibit interaction with myosin.
2. Troponin-T
   a. MW = 37 kD
   b. Troponin T binds to tropomyosin.
3. Troponin-C
   a. MW = 15 kD
   b. Troponin C binds Ca^{++}.

C. Tropomodulin

1. < 1% of total myofibrillar proteins
2. MW = 41 kD
3. Located at free end of actin.
4. Tropomodulin restricts the growth of F-actin.

D. Cap Z

1. MW = 66 kD
2. Cap Z binds to F-actin and inhibits G-actin polymerization.

V. Cytoskeletal proteins

A. Titin (Connectin)

1. 10% of total myofibrillar proteins
2. MW = 3.7×10^3 kD
3. Titin extends in each half sarcomere from the M line to the Z disk.
   a. The portion of titin in the A band is inelastic.

b. The portion of titin in the I band is elastic.

c. Titin is bound outside the shaft of thick filament.

4. Titin influences elasticity of the sarcomere.

B. Nebulin

1. 4% of total myofibrillar proteins
2. MW = 773 kD
3. Extends along the entire length of the thin filament from A band to Z disk.
2. Helps to align thin filaments during myofibril formation.
3. May also anchor thin filaments to Z disk.

C. C-Protein

1. 2% of total myofibrillar protein
2. MW = 130 kD
3. Clamps around thick filament (like barrel hoop).

a. May inhibit ATPase activity.

b. 40 C-protein molecules/thick filament

c. 7 C-protein bands on each side of the H-zone

D. M-Line proteins (< 2% of total myofibrillar proteins)

1. M protein and myomesin

a. Project from thick filaments at M-line.

b. Stabilize central portion of thick filaments.

2. Metabolic proteins

a. Glycogen debranching enzyme

b. Creatine kinase

c. Myomesin -- connects adjacent thick filaments.

VI. Z-Disk proteins

A. α-Actinin

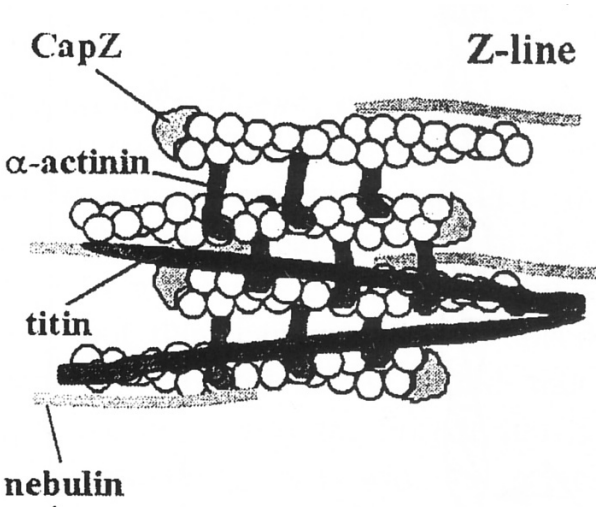
1. 2% of total myofibrillar proteins.
2. MW = exists as dimer of 190 kD.
3. Anchors thin filaments.

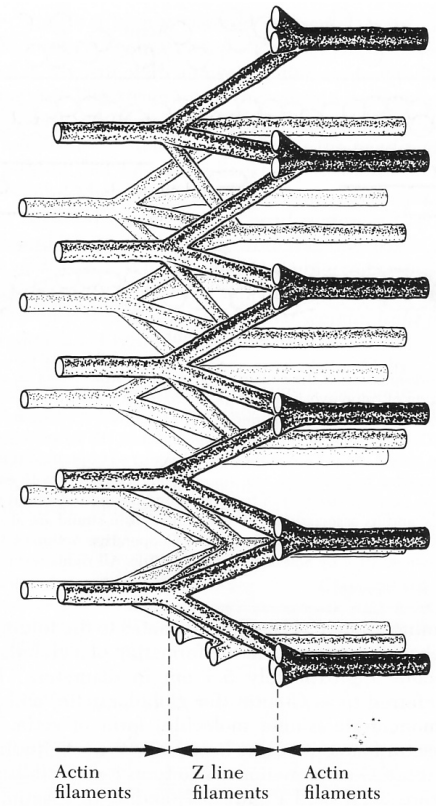
B. Desmin

1. MW = 212 kD
2. Functions to connect adjacent myofibrils.
3. Radiates from Z-line to adjacent Z-line.

C. Other proteins of the Z-disk

1. Filamen
2. Synemin
3. Vinculin
4. CapZ





VII. Intermyofibrillar proteins

A. Desmin

1. Desmin filaments can be seen as connections between adjacent Z-lines.
2. Desmin filaments keep sarcomeres in register.

B. Costameres

1. Costameres attach sarcomeres to the sarcolemma.
2. Transmit force of contraction from the myofibrils to the body of the muscle.

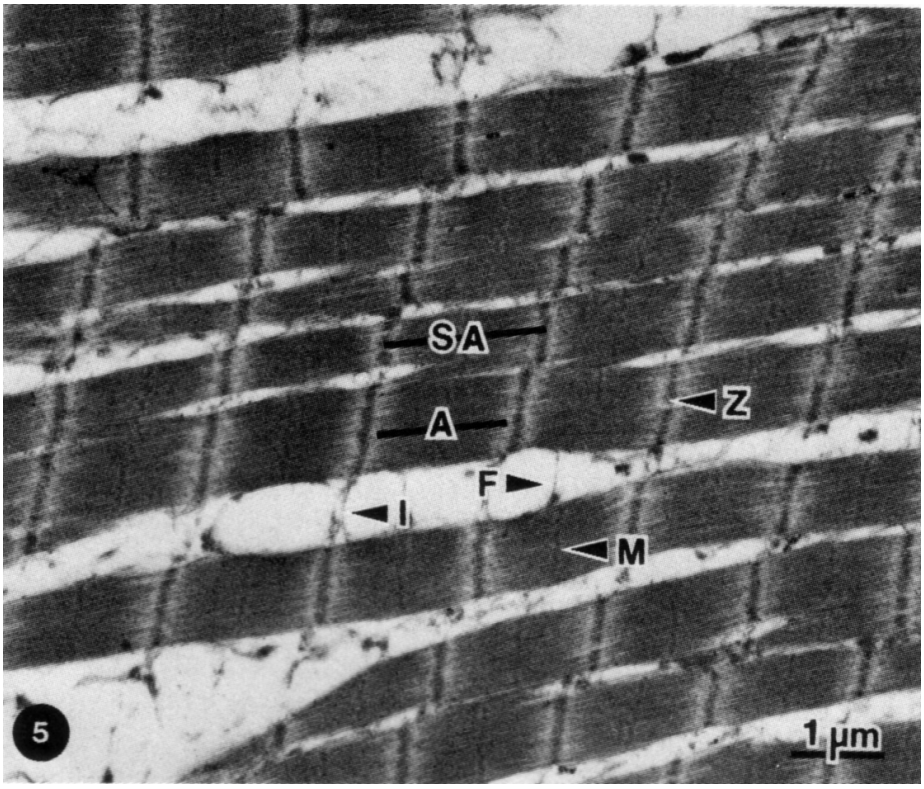
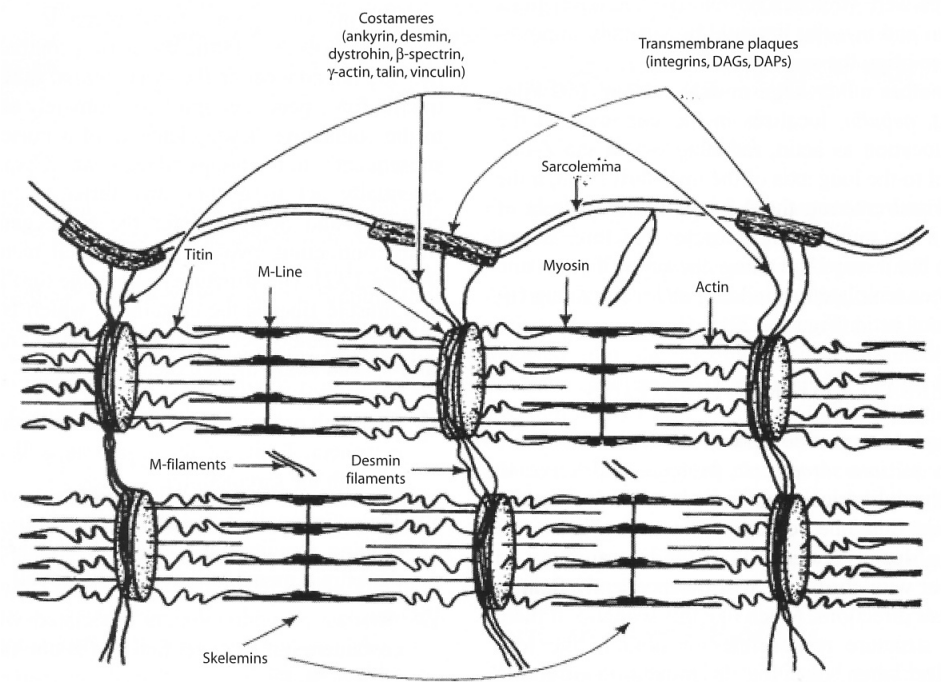


Fig. 5. Transmission electron micrograph of restrained bovine sternomandibularis muscle placed in 3% glutaraldehyde fixative for 24 hours. Intermyofibrillar bridges (I) join adjacent myofibrils at the Z-lines (Z). The sarcomeres (SA) are extremely short, with Z-lines almost touching each edge of the A-bands (A). The M-line (M) is easily discerned. Filaments (F) join adjacent myofibrils at the A-band region.



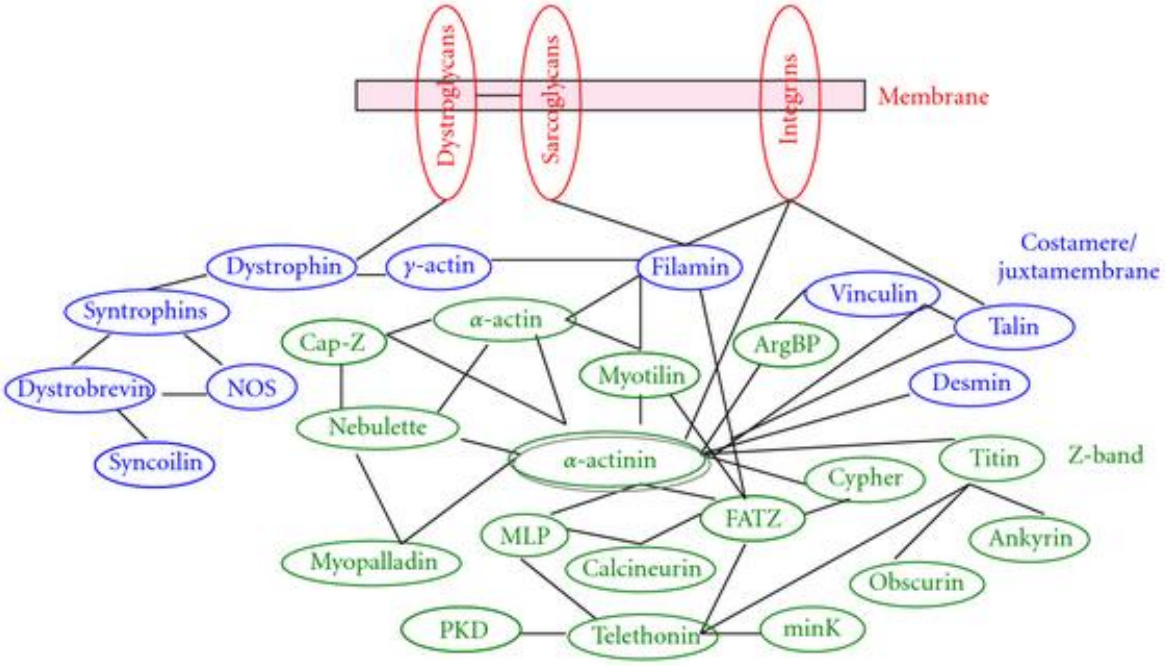


Diagram of some proteins related to be in the Z-bands of mature myofibrils. The Z-bands of the mature myofibrils are attached via costameric proteins to the membranes of the muscle cells.