The Motor Unit and Muscle Action

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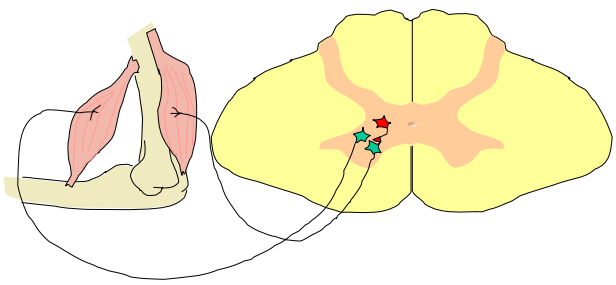
Three types of muscles

Smooth muscle: internal actions such as peristalsis and blood flow.

Cardiac muscle: pumping blood.

Skeletal muscle: moving bones.

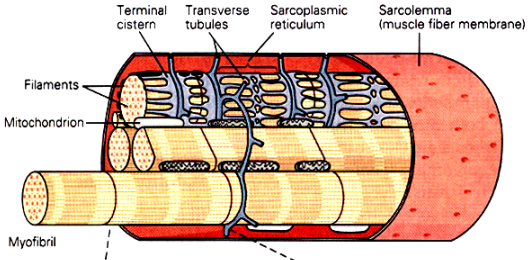
A motor unit consists of a motor neuron and the muscle fibers that it innervates.

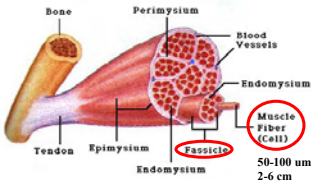


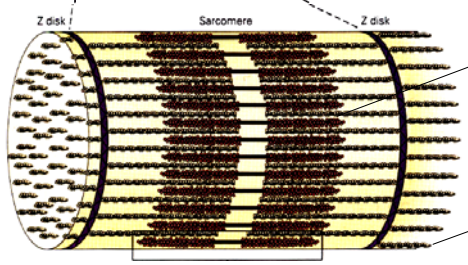
Skeletal muscle fibers are innervated by α-motor neurons.

The Skeletal Muscle - Organization

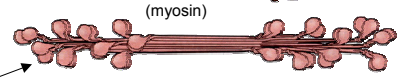
Muscle→ Fascicles → Muscle Fibers → Myofibrils







Thick filament (myosin)



Thin filament (f-actin, tropomyosin, troponin)

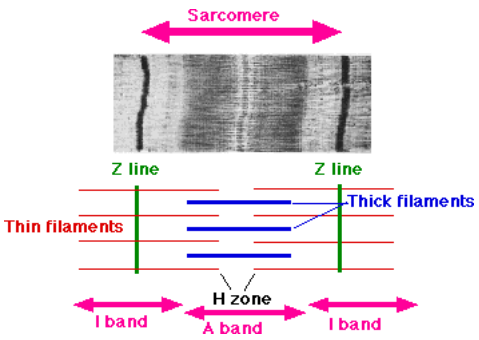
The Skeletal Muscle - Organization

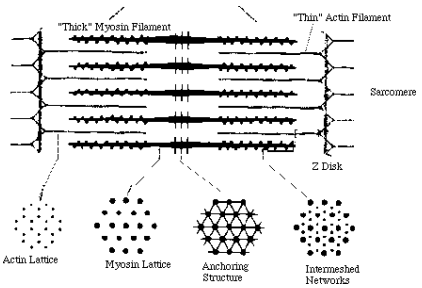
Muscle Unit→ Ensemble of muscle fibers innnervated by the same motor neuron

Motor Unit→ A muscle unit together with the motor neuron that innervates it.

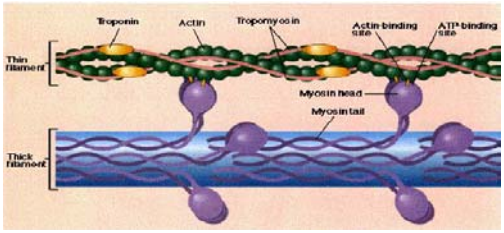
Except during development, each muscle fiber is only innervated by one motor neuron in one place (in mammals).

The Sarcomere is the contractile Unit of the Striated Muscle





The Thick Filament

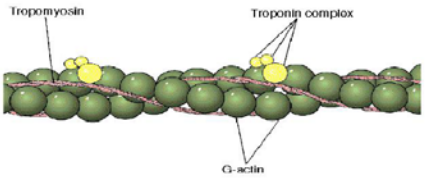


Thick filaments are composed of a protein called myosin. Each myosin molecule has a tail which forms the core of the thick filament plus a head that projects out from the core of the filament. These myosin heads are also commonly referred to as cross-bridges.

The myosin head has several important characteristics:

1) it has ATP-binding sites into which fit molecules of ATP. ATP represents potential energy.
2) it has actin-binding sites into which fit molecules of actin.
3) it has a "hinge"at the point where it leaves the core of the thick filament. This allows the head to swivel back and forth, and the "swiveling" is, as will be described shortly, what actually causes muscle contraction.

The Thin Filament



The actin molecules (or G-actin as above) are spherical and form long chains. Each thin filament contains two such chains that coil around each other.
Tropomyosin molecules are long, thin molecules that wrap around the chain of actin.
At the end of each tropomyosin is an troponin molecule. The tropomyosin and troponin molecules are connected to each other.

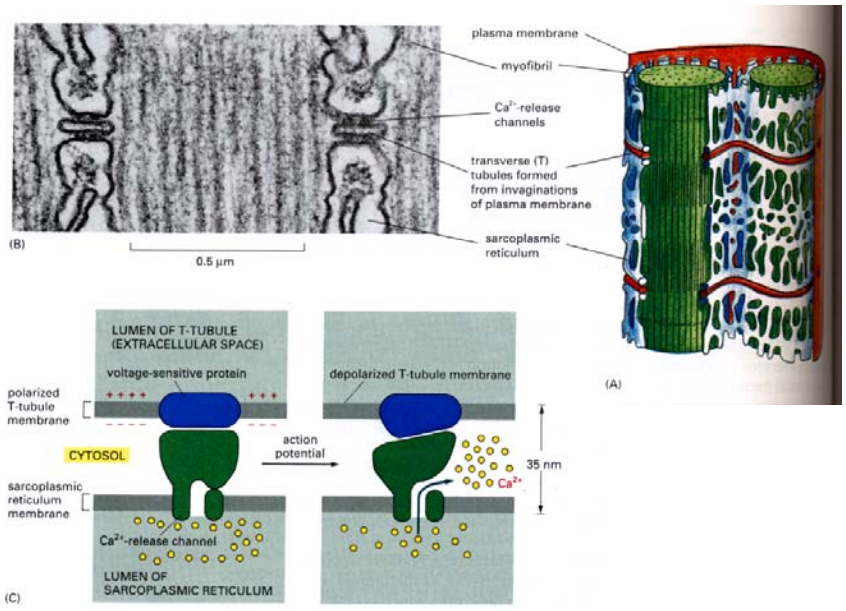
Each of these 3 proteins plays a key role in muscle contraction:

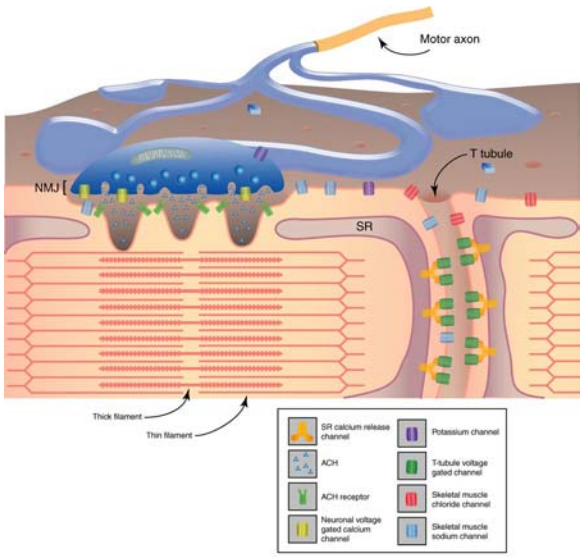
ACTIN - when actin combines with myosin head, the ATP associated with the head breaks down into ADP. This reaction releases energy that causes the myosin head to swivel.

TROPOMYOSIN - In a relaxed muscle, the myosin heads of the thick filament lie against tropomyosin molecules of the thin filament. As long as the myosin heads remain in contact with tropomyosin nothing happens (i.e., a muscle remains relaxed).

TROPONIN - Troponin molecules have binding sites for calcium ions. When a calcium ion fills this site it causes a change in the shape and position of troponin. And, when troponin shifts, it pulls the tropomyosin to which it is attached. When tropomyosin is moved, the myosin head that was touching the tropomyosin now comes in contact with an underlying actin molecule.

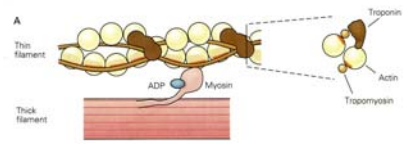
Excitation – Contraction Coupling I: The t-tubules and the SR



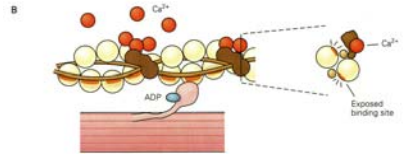


Excitation – Contraction Coupling II: The cross-bridge cycle

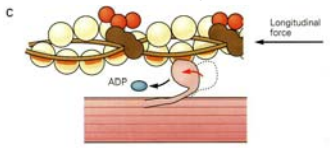
Attached (rest)



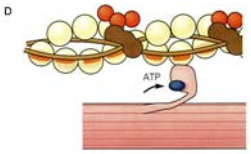
Cross bridge formation



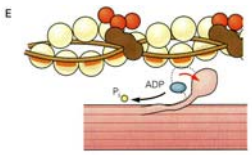
Head rotation and force generation



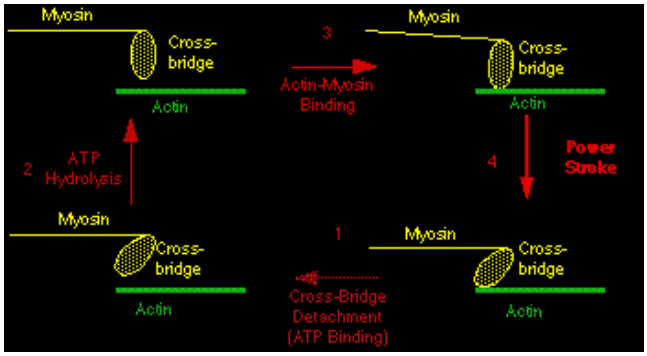
ATP-binding



ATP hydrolysis and Recock of myosin head



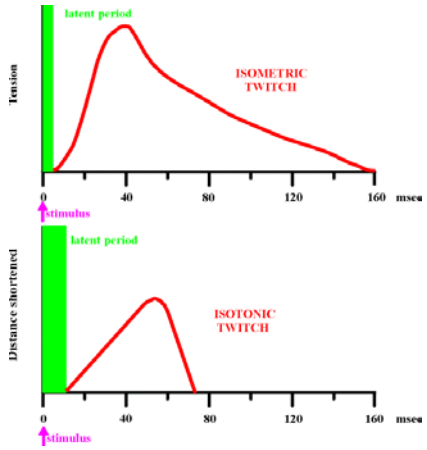
Excitation – Contraction Coupling II: The cross-bridge cycle



Type of contractions

1 - isotonic - tension or force generated by the muscle is greater than the load & the muscle shortens (successfully lift up a bucket or water)

2 - isometric - load is greater than the tension or force generated by the muscle & the muscle does not shorten (tried to lift up a bucket of water but failed)



Each single AP of the nerve elicit a single muscle twitch, which contains:

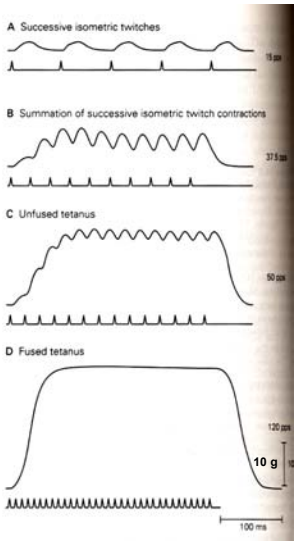
Latent period

Contraction period

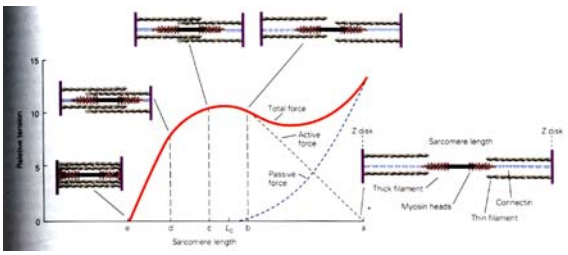
Relaxation period

The force of the contraction of a muscle depends on:

1- The frequency of the action potentials fired



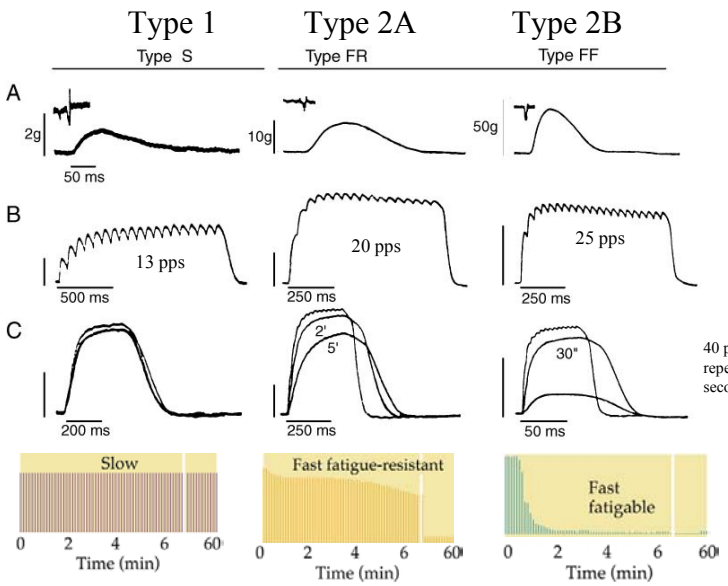
2- The muscle fibers' lengths (which depend on the initial overlap between thick and thin fibers)



Active force: dependent on the degree of overlap of thick and thin filament.

Passive force: generated when lengthening the connectin filaments that tether the thick filaments between the z disks

Three types of muscle units



40 pps for 0.33 s, repeated every second

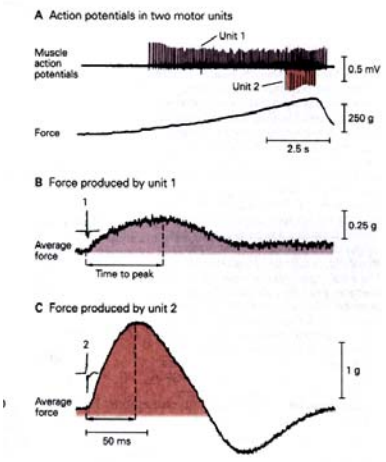
Types of Striated Muscle/ Types of Muscle Fibers:

	Red	White	
Fiber type	Slow –twitch fibers (type I)	fast-fatigable (type IIB)	fast-fatigue resistant (type IIA)
Fiber Size	small	large	large (but maybe not as large as type IIB)
Force	small	large	intermediate
Contraction Speed	slow	fast	fast
Mitochondria	many	very little	intermediate
Oxidative capacity	high	low	moderate to high
Fatigue	Fatigue resistant	easy fatigable	fatigue resistant (though less than type I)
'typical usage'	posture	gallop, jump	run

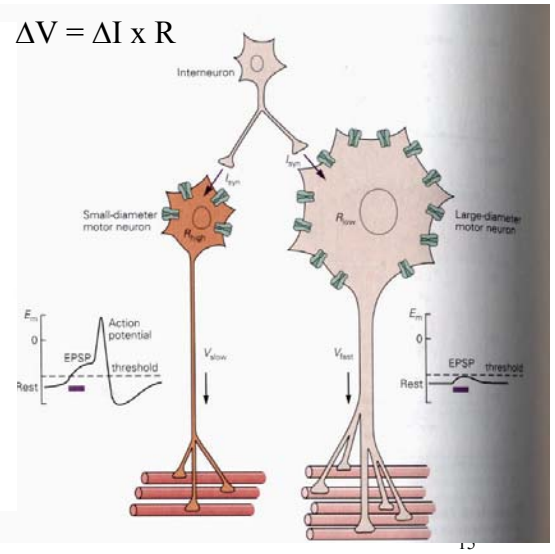
The MN that innervates fast-twitch muscle fibers usually innervates many large fibers. These MN have relatively large cell bodies and large axon diameters, so they can conduce action potentials fast. (the opposite is true for those MN that innervate the small fibers)

The Motor Units are Recruited in a fixed order

Example of recruitment of two motor units



The size principle of MN recruitment



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