Biomechanics of Skeletal Muscle (incomplete notes)

M1

Muscle Mechanics

Structure of muscle

Microstructure (see Fig 5-1)

Macrostructure – many filaments in parallel and many sarcomere elements in series combine to make a single ____ ____ or contractile component of a ____ total muscle. The ____ the x-sectional area of muscle, the ____ ____ it can develop (in general).

Motor unit (MU) = the smallest subunit of a muscle that can be controlled – it is separately innervated by a motor axon.

MU may have as few as ____ or as many as ____ muscle fibers – more control needed – fewer fibers per MU.

Stimulating muscle action (see Fig 5-6 & 5-7)

Recruitment see Winter (1990) Figure 7.3 → Supplemental Reading Ch7 in: Winter D.A. (1990). Biomechanics and Motor Control of Human Movement (copy in PEBE 107B)

Components of muscle / Mechanical models

____ = Contractile component

____ = Parallel elastic component (connective tissue surrounding muscle)

____ = Series elastic component (tendons)

____ = Viscous component (fluid resistance within muscle)

M2

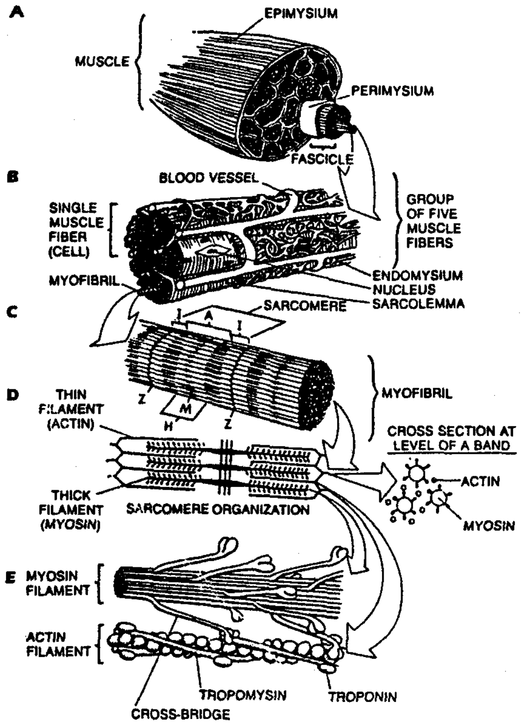


FIG. 5–1

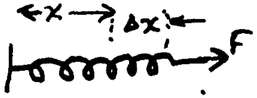
Schematic drawings of the structural organization of muscle. **A.** A fibrous connective tissue fascia, the epimysium, surrounds the muscle, which is composed of many bundles, or fascicles. The fascicles are encased in a dense connective tissue sheath, the perimysium. **B.** The fascicles are composed of muscle fibers, which are long, cylindrical, multinucleated cells. Between the individual muscle fibers are capillary blood vessels. Each muscle fiber is surrounded by a loose connective tissue called the endomysium. Just beneath the endomysium lies the sarcolemma, a thin elastic sheath with infoldings that invaginate the fiber interior. Each muscle fiber is composed of numerous delicate strands, myofibrils, the contractile elements of muscle. **C.** Myofibrils consist of smaller filaments, which form a repeating banding pattern along the length of the myofibril. One unit of this serially repeating pattern is called a sarcomere. The sarcomere is the functional unit of the contractile system of muscle. **D.** The banding pattern of the sarcomere is formed by the organization of thick and thin filaments, composed of the proteins myosin and actin, respectively. The actin filaments are attached at one end but are free along their length to interdigitate with the myosin filaments. The thick filaments are arranged in a hexagonal fashion. A cross section through the area of overlap shows the thick filaments surrounded by six equally spaced thin filaments. **E.** The lollipop-shaped molecules of each myosin filament are arranged so that the long tails form a sheaf with the heads, or cross-bridges, projecting from it. The cross-bridges point in one direction along half of the filament and in the other direction along the other half. Only a portion of one half of a filament is shown here. The cross-bridges are an essential element in the mechanism of muscle contraction, extending outward to interdigitate with receptor sites on the actin filaments. Each actin filament is a double helix, appearing as two strands of beads spiraling around each other. Two additional proteins, tropomyosin and troponin, are associated with the actin helix and play an important role in regulating the interdigitation of the actin and myosin filaments. Tropomyosin is a long polypeptide chain that lies in the grooves between the helices of actin. Troponin is a globular molecule attached at regular intervals to the tropomysin. (Adapted from Williams and Warwick, 1980.)

Biomechanics of Skeletal Muscle (incomplete notes)

symbols for various elements


(spring) = elastic element

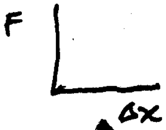
x = resting length



Linear spring

k = ________

Δx = ________

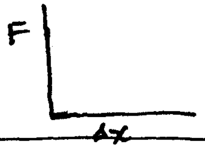


However

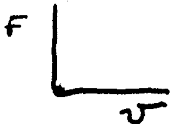
Not all springs are linear —

where a can vary from 1.0

e.g. if a=2




(dashpot) = viscous element



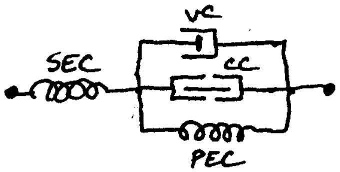
linear dashpot

v = ________

Nonlinear dashpot :

Eg if c=2

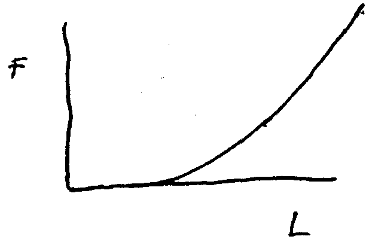
= simpler drawing of force generator element than your book uses



More consistent with Winter's diagrams

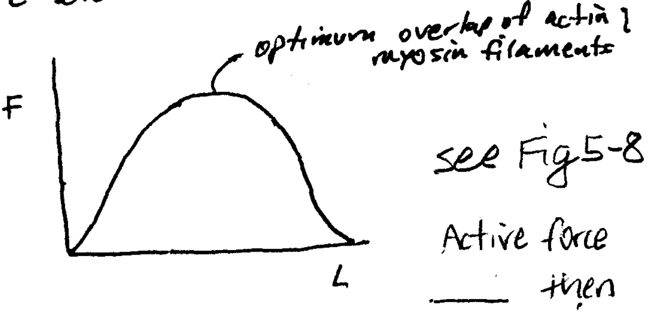
Force length relationship for skeletal muscle (length-tension ") measured statically $v=0$

Passive elements' contribution primarily from ____ & ____



(Passive) ↑ Force ____ with ________ ____.

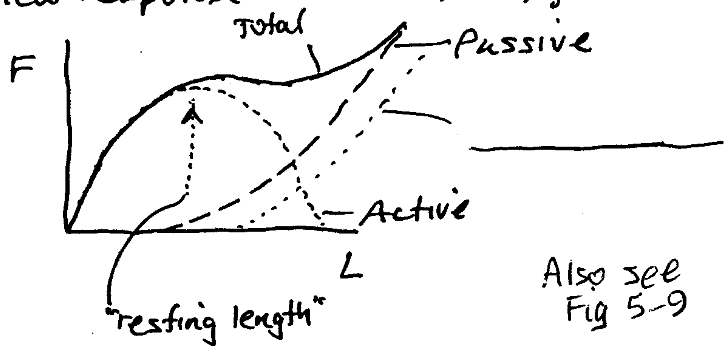
Active elements' contribution (CC)



see Fig 5-8

Active force ____ then ____ with ________ ____.

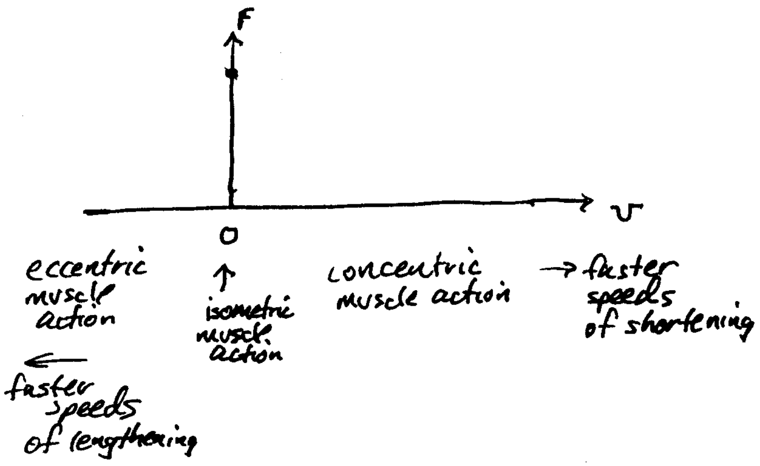
Combined response of SEC, PEC, & CC



Also see Fig 5-9

From stretching & flexibility exercises, one can move the passive curve farther to the right

Force - _____ relationships



Influence of viscous element on forces at various speeds of shortening & lengthening

VC produces resistive forces which are _____ _____ _____ (not length) i.e. faster = more resistive force

_____ actions: _____ is trying to shorten the muscle _____ is resisting the _____ (similar to friction). The force produced by the VC _____ from that produced by the CC. - so force in tendon is _____ than that produced by the _____.

$$\overrightarrow{F_{CC}} + \overleftarrow{F_{VC}} = \overrightarrow{F_T}$$

_____ actions: _____ is _____ the external force which is trying to lengthen the muscle. The VC adds _____ - so the force in the tendon is _____ than the force in the CC.

$$\underrightarrow{F_{CC}} + \underrightarrow{F_{VC}} = \underrightarrow{F_T}$$

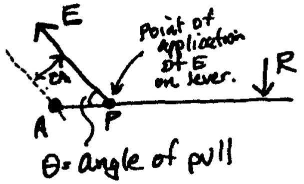
M7

Within the CC, the act of forming and breaking actin & myosin bonds tends to reduce the force with the muscle compared to the isometric case where the bonds hold steady.

The opposite appears to be true when the cross bridges are broken during eccentric action — somehow the CC can produce ______ ______ when lengthening as opposed to isometric.

Combined effect of force-length & force velocity see Winter Figure 7.13

How muscles apply moments or torque about joints.



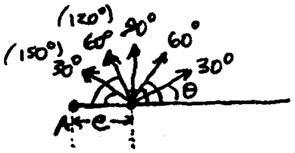
E = "Effort force" (muscle force)

EA = moment arm of muscle force about axis A

M_A (from muscle force) $= E \cdot EA$

Force × moment arm

Moment arm changes as   changes.



"Leverage" = "moment arm"

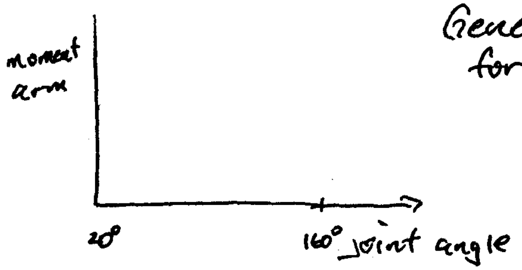
$EA = e \sin\theta$

$EA = e$ only when $\theta = 90°$

otherwise

$EA < e$

M8



General pattern for many muscles

As a result — one feels (______) at certain joint angles relative to others because of 2 factors:

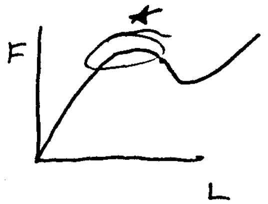
Able to produce larger moment about a joint

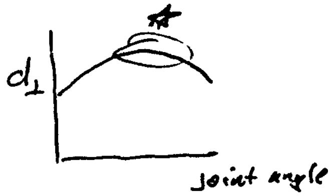
(F) 1. Force-length relationship (muscle ______ changes with changes in muscle length)

($d_\perp$) 2. " ______ " — moment arm changes with changes in joint angle.

$M_A =$

Moment = ______





*Note: The peaks may or may not coincide for a given muscle

Especially for muscles that cross two or more joints – The muscle length here is influenced by the joint angles of all joints "crossed".

For example: Biceps "crosses" 3 joints

1. ________ 2. ________ 3. ________.

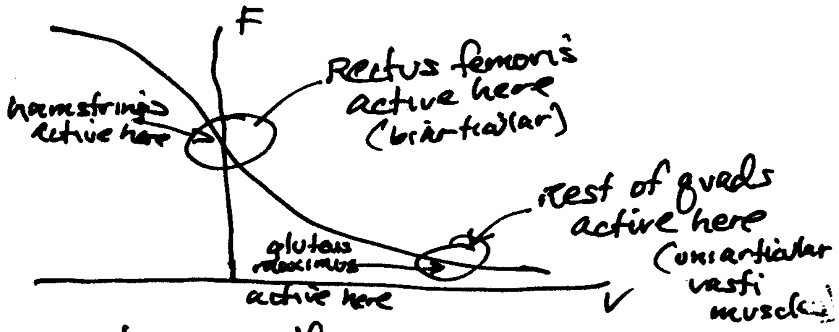
Biceps loses muscle activation potential when forearm is pronated – this is in addition to changes in muscle length from pronation (increase in length).

Benefits of 2 joint muscles ("________ muscles" and >2 joint ("________ muscles")

Example: Hip & Knee joints

Hamstrings & Quads (________ specifically)

During combined knee extension + hip extension (rising from a squat – or the downstroke of the crank in cycling) the hamstrings & rectus femoris are basically active ________ (lengthening at one end and shortening at the other) while motion is occurring.



During rapid knee + hip extension

________ : If both flexor and extensor muscles are active at the same time (e.g. knee: rectus femoris tending to extend, hamstrings tending to flex) – How does any joint motion occur?

Possibilities:

1. Non-simultaneous action of 2 muscle groups involved
2. Different moment arms of 2 muscle groups about the joint in question.

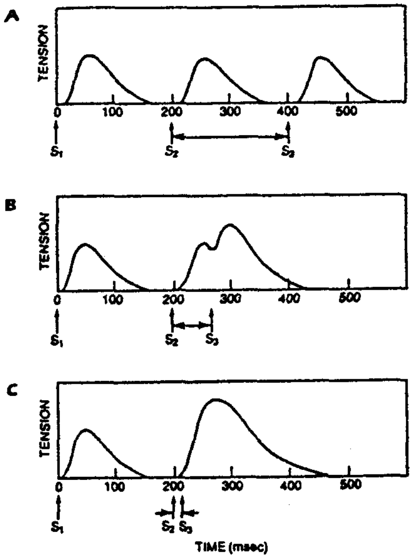


FIG. 5–6
Summation of contractions in a muscle held at a constant length. **A.** An initial stimulus (S_1) is applied to the muscle, and the resulting twitch lasts 150 msec. The second (S_2) and third (S_3) stimuli are applied to the muscle after 200-msec intervals when the muscle has relaxed completely; thus no summation occurs. **B.** S_3 is applied 60 msec after S_2, when the mechanical response from S_2 is beginning to decrease. The resulting peak tension is greater than that of the single twitch. **C.** The interval between S_2 and S_3 is further reduced to 10 msec. The resulting peak tension is even greater than in **B**, and the increase in tension produces a smooth curve. The mechanical response evoked by S_3 appears as a continuation of that evoked by S_2. (Adapted from Luciano et al., 1978.)

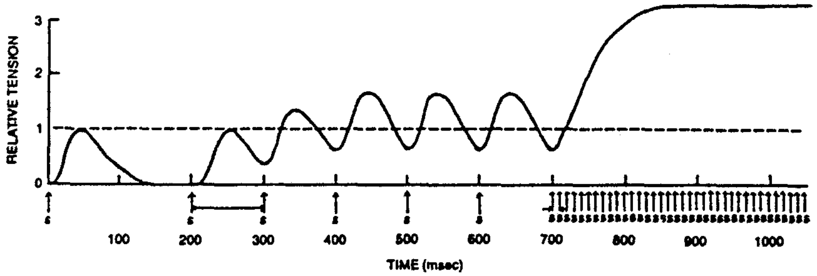


FIG. 5–7
Generation of muscle tetanus. As the frequency of stimulation (S) increases (i.e., the intervals shorten from 200 to 100 msec), the muscle tension rises as a result of summation. When the frequency is increased to 100 per second, summation becomes maximal and the muscle *contracts tetanically, exerting sustained peak tension. (Adapted from Luciano et al., 1978.)*

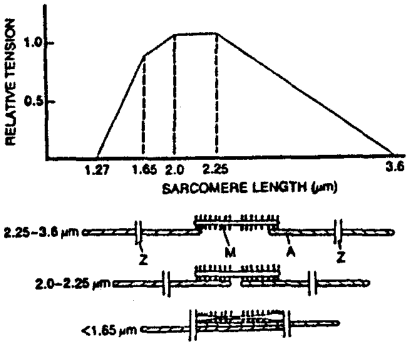


FIG. 5–8
Tension-length curve from part of an isolated muscle fiber stimulated at different lengths. The isometric tetanic tension is closely related to the number of cross-bridges on the myosin filament overlapped by the actin filament. The tension is maximal at the slack length, or resting length, of the sarcomere (2 μm), where overlap is greatest, and falls to zero at the length where overlap no longer occurs (3.6 μm). The tension also decreases when the sarcomere length is reduced below the resting length, falling sharply at 1.65 μm and reaching zero at 1.27 μm, as the extensive overlap interferes with cross-bridge formation. The structural relationship of the actin and myosin filaments at various stages of sarcomere shortening and lengthening is portrayed below the curve. A, actin filaments; M, myosin filaments; Z, Z lines. (Adapted from Crawford and James, 1980, as modified from Gordon et al., 1966b.)

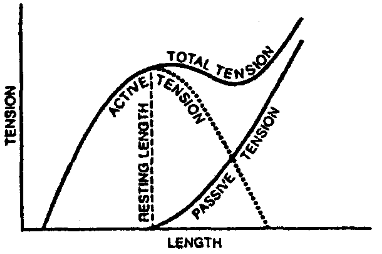


FIG. 5–9
The active and passive tension exerted by a whole muscle *contracting isometrically and tetanically is plotted against the* muscle's length. The active tension is produced by the contractile muscle components and the passive tension by the series and parallel elastic components, which develop stress when the *muscle is stretched beyond its resting length. The greater the* amount of stretching, the larger is the contribution of the elastic component to the total tension. The shape of the active curve is generally the same in different muscles, but the passive curve, and *hence* the total curve, varies *depending* on *how much* connective tissue (elastic component) the muscle contains. (Adapted from Crawford and James, 1980.)

From Winter (1990)

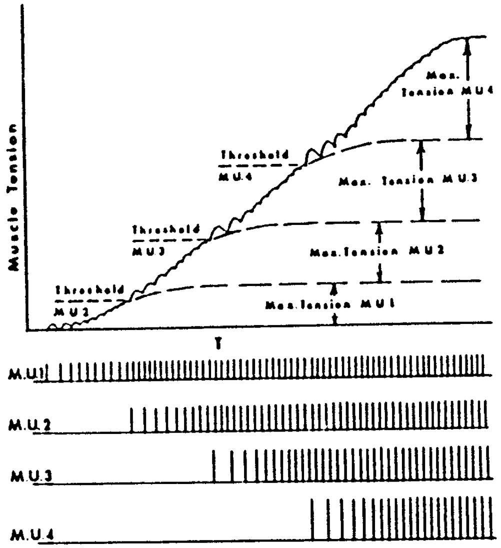


Figure 7.3 Size principle of recruitment of motor units. Smaller motor units are recruited first; successively larger units begin firing at increasing tension levels. In all cases the newly recruited unit fires at a base frequency, then increases to a maximum.

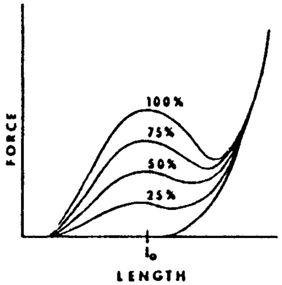


Figure 7.9 Tendon tension resulting from various levels of muscle activation. Parallel elastic element generates tension independent of the activation of the contractile element.

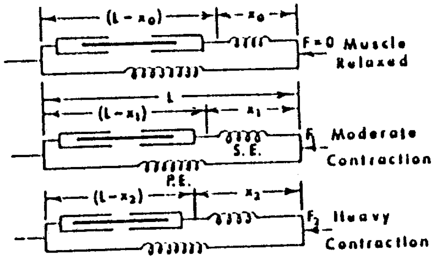


Figure 7.10 Introduction of the series elastic (S.E.) element. During isometric contractions the tendon tension reflects a lengthening of the series element and an internal shortening of the contractile element. During most human movement the presence of the series elastic element is not too significant, but during high-performance movements such as jumping it is responsible for storage of energy as a muscle lengthens immediately prior to rapid shortening.

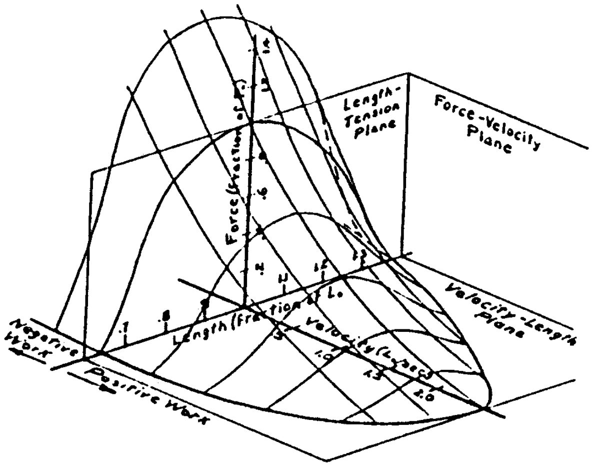


Figure 7.13 Three-dimensional plot showing the change in contractile element tension as a function of both velocity and length. Surface shown is for maximum muscle activation; a new "surface" will be needed to describe each level of activation. Influence of parallel elastic element is not shown.