Chapter 6

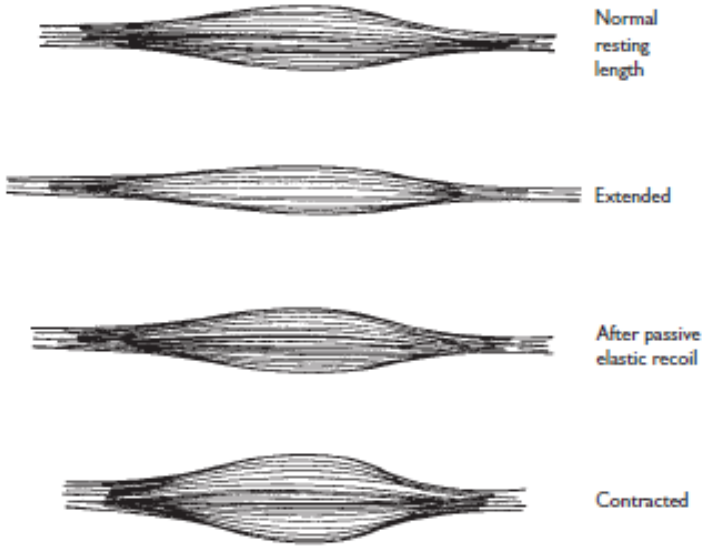
The Biomechanics of Human Skeletal Muscle

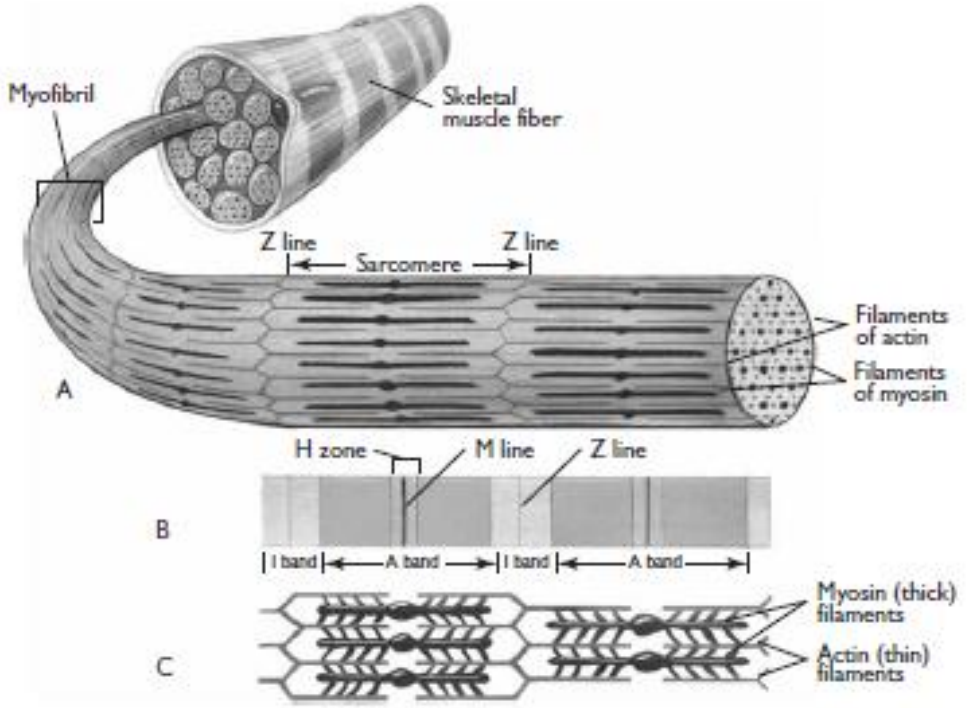
Basic Biomechanics, 6th edition
By Susan J. Hall, Ph.D.

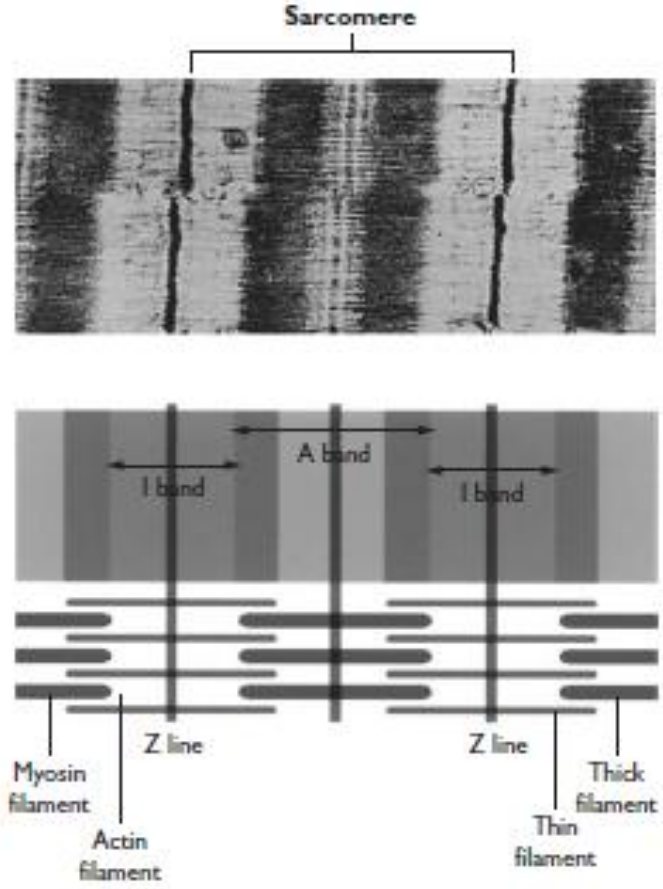
Behavioral Properties of the Musculotendinous Unit

What is the stretch-shortening cycle?

- Åeccentric contraction (in which the muscle is actively stretched) followed immediately by concentric contraction
- ÅCan you think of examples?


Normal resting length
Extended
After passive elastic recoil
Contracted


Myofibril
Skeletal muscle fiber
Z line
Sarcomere
Z line
Filaments of actin
Filaments of myosin
A
H zone
M line
Z line
B
I band
A band
I band
A band
Myosin (thick) filaments
Actin (thin) filaments
C

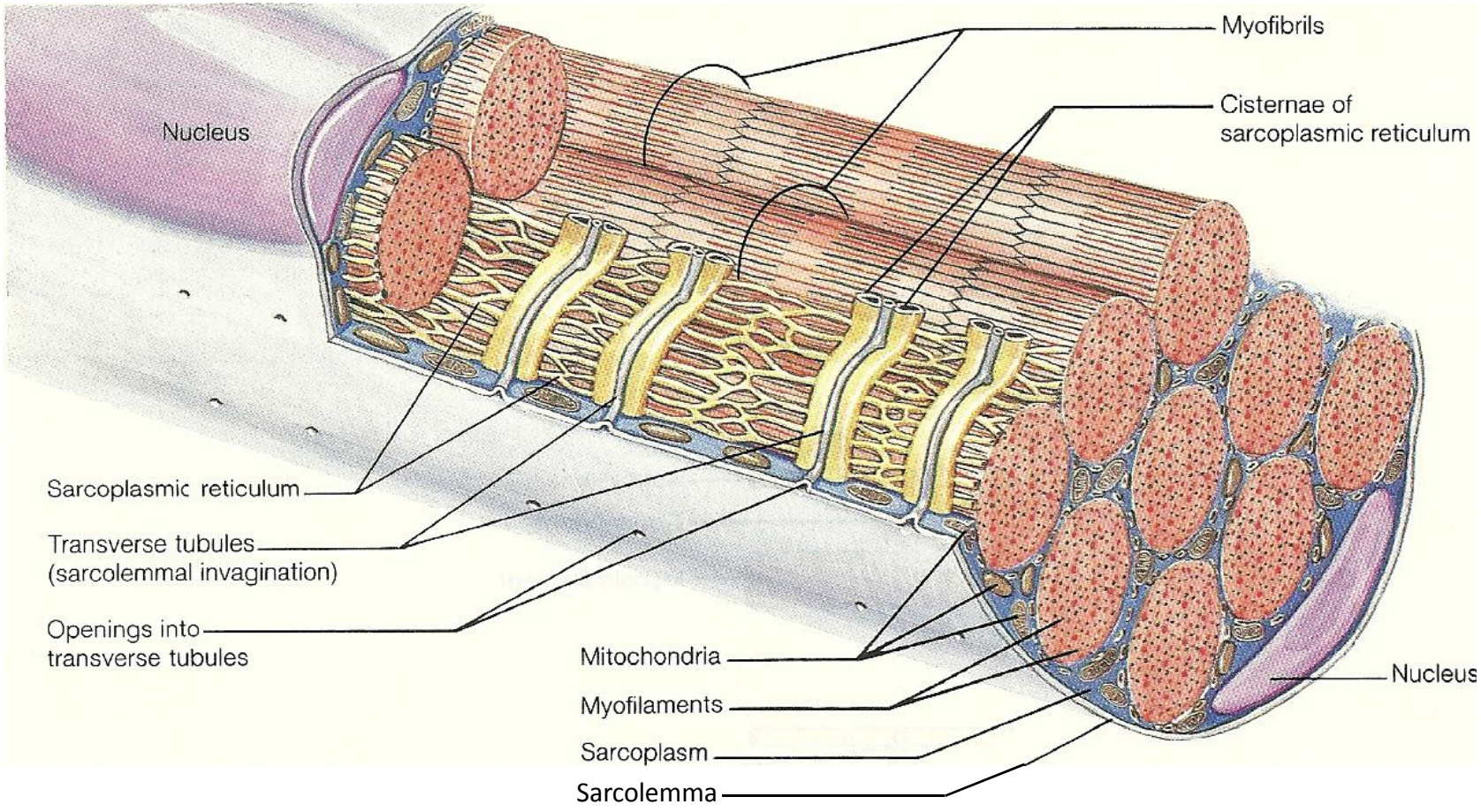

Sarcomere
A band
I band
I band
Z line
Z line
Myosin filament
Actin filament
Thin filament
Thick filament

Structural Organization of Skeletal Muscle

What is a muscle fiber?

(single muscle cell surrounded by a membrane called the sarcolemma and containing specialized cytoplasm called sarcoplasm)

Structural Organization of Skeletal Muscle



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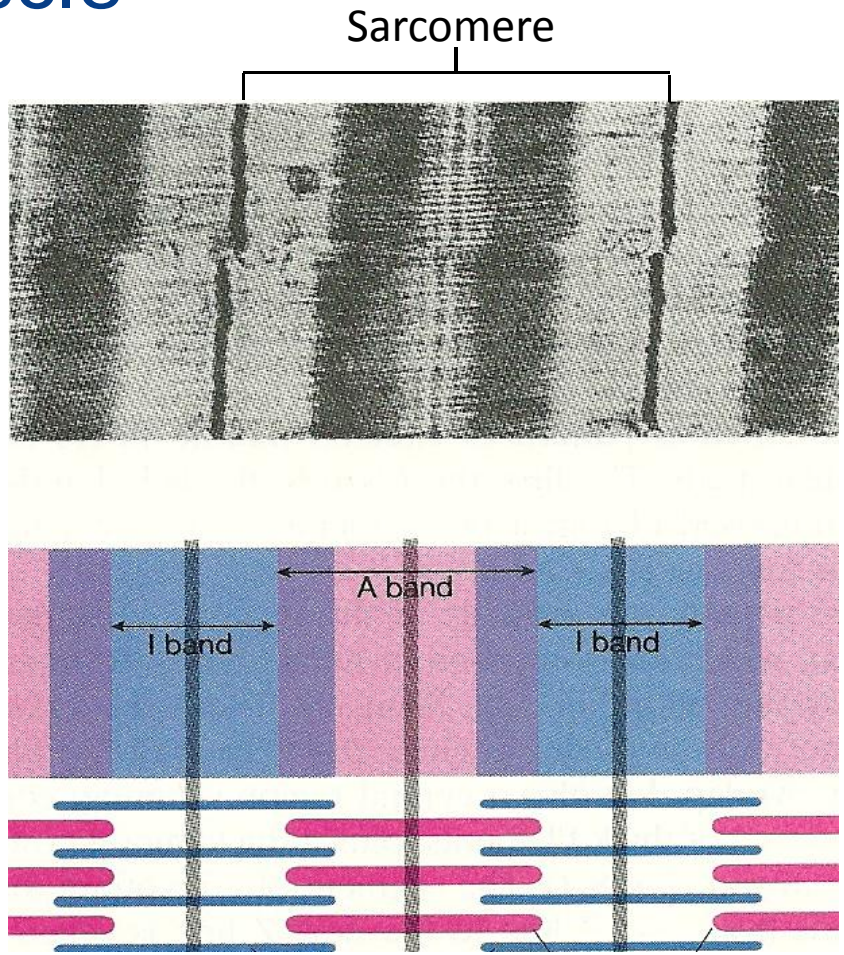
Structural Organization of Skeletal Muscle

What do we know about muscle fibers?

- Some fibers run the entire length of a muscle; others are shorter
- Skeletal muscle fibers grow in both length and diameter from birth through adulthood
- Fiber diameter can be increased through resistance training

Structural Organization of Skeletal Muscle

The sarcomere is the basic structural unit of the muscle fiber. The alternating dark and light bands give muscle its striated appearance. The A bands contain thick, rough myosin filaments surrounded by six thin, smooth actin filaments. The I bands contain only thin actin filaments.



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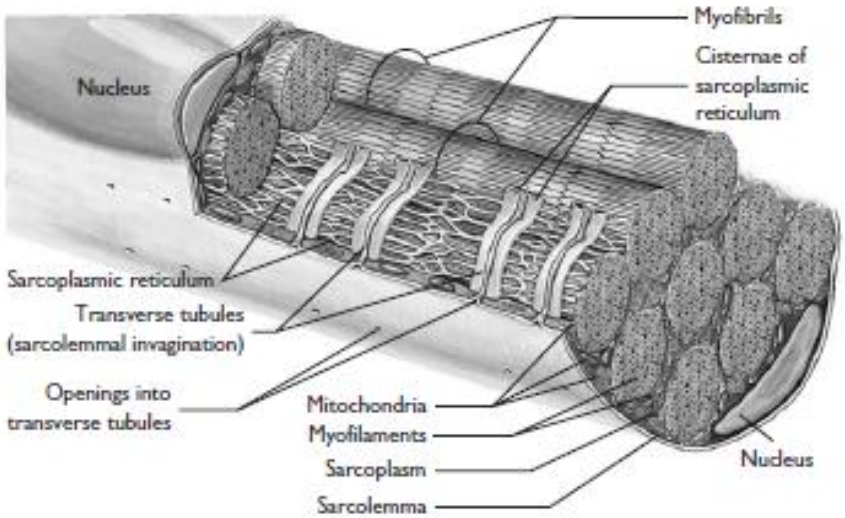
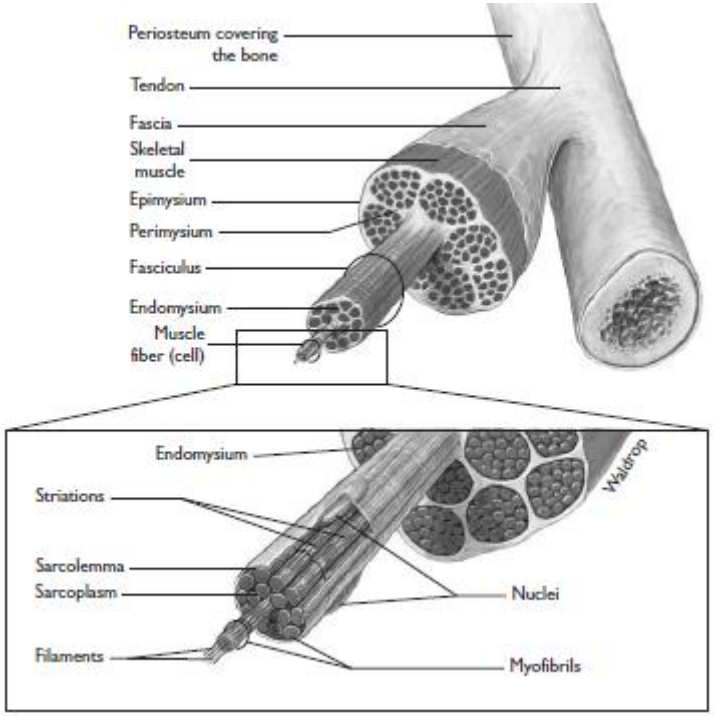

Myofibrils
Cisternae of sarcoplasmic reticulum
Nucleus
Sarcoplasmic reticulum
Transverse tubules (sarcolemmal invagination)
Openings into transverse tubules
Mitochondria
Myofilaments
Sarcoplasm
Sarcolemma
Nucleus


Periosteum covering the bone
Tendon
Fascia
Skeletal muscle
Epimysium
Perimysium
Fasciculus
Endomysium
Muscle fiber (cell)
Endomysium
Striations
Sarcolemma
Sarcoplasm
Filaments
Nuclei
Myofibrils
Waldrop

Structural Organization of Skeletal Muscle

What is a motor unit?

- single motor neuron and all fibers it innervates
- considered the functional unit of the neuromuscular system

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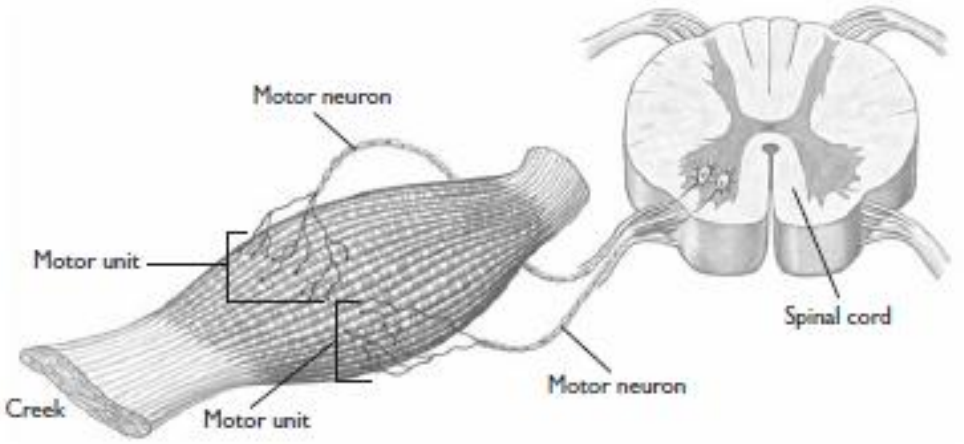
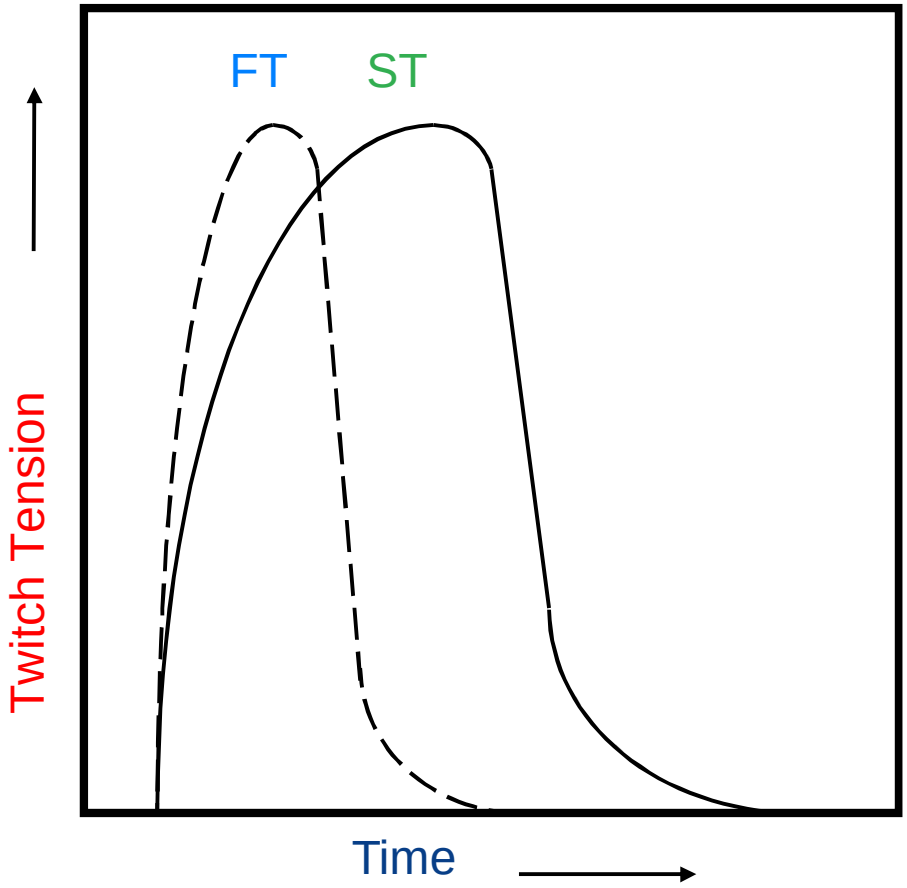

Motor neuron
Motor unit
Spinal cord
Motor neuron
Creek
Motor unit


Motor nerve
Motor neuron axon
Muscle fiber
Motor end plate

Structural Organization of Skeletal Muscle

Fast twitch (FT) fibers both reach peak tension and relax more quickly than slow twitch (ST) fibers. (Peak tension is typically greater for FT than for ST fibers.)



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Skeletal Muscle Fiber Characteristics

CHARACTERISTIC	Type I Slow-Twitch Oxidative (SO)	TYPE IIA Fast-Twitch Oxidative Glycolytic (FOG)	Type IIB Fast-Twitch Glycolytic (FG)
Contraction Speed	slow	fast	fast
Fatigue rate	slow	intermediate	fast
Diameter	small	intermediate	large
ATPase concentration	low	high	high
Mitochondrial concentration	high	high	low
Glycolytic enzyme concentration	low	intermediate	high

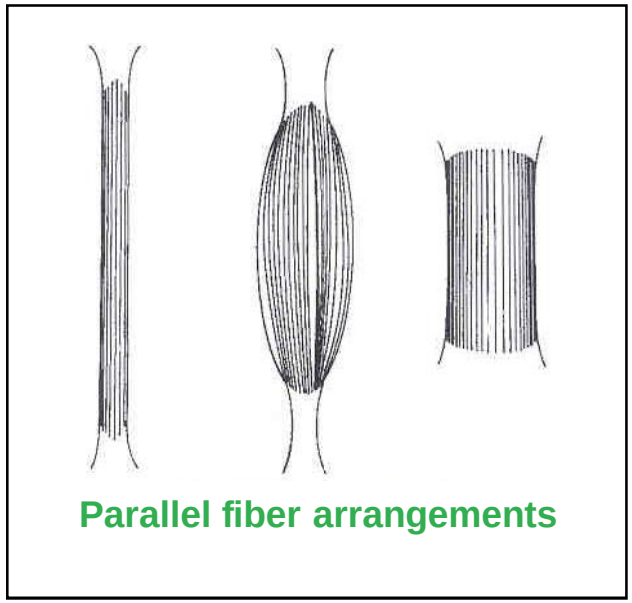
Structural Organization of Skeletal Muscle

How are muscle fibers organized?

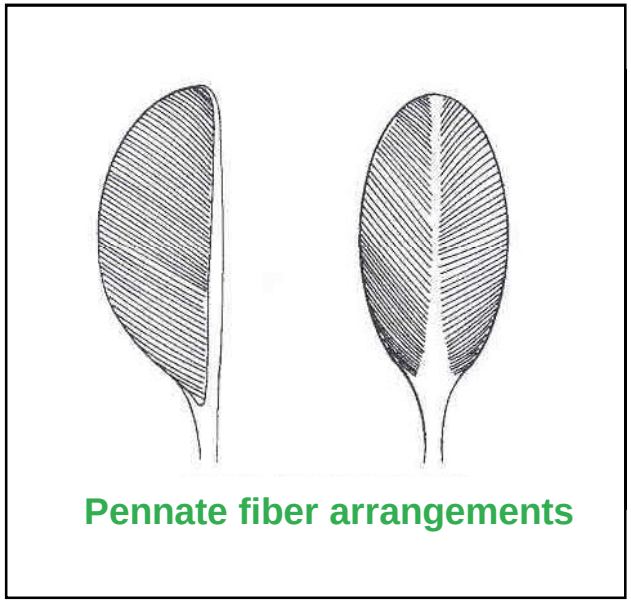
Åparallel fiber arrangement: fibers are roughly parallel to the longitudinal axis of the muscle; examples are?

Åpennate fiber arrangement: short fibers attach to one or more tendons within the muscle; examples?

Structural Organization of Skeletal Muscle



Parallel fiber arrangements



Pennate fiber arrangements

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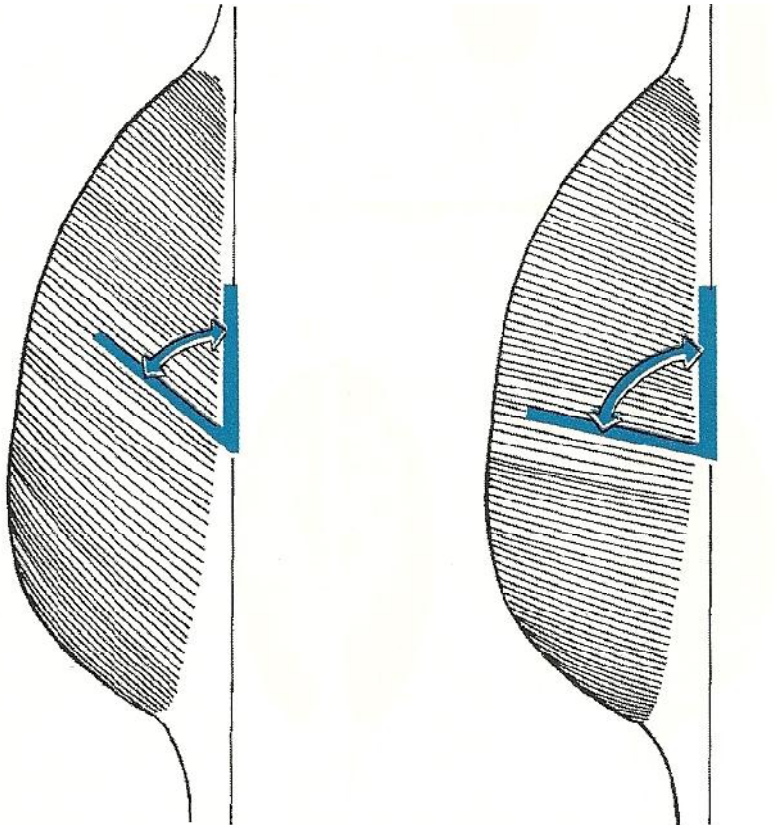
Structural Organization of Skeletal Muscle



Relaxed

With tension development

The angle of pennation increases as tension progressively increases in the muscle fibers.

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SAMPLE PROBLEM 6.1

How much force is exerted by the tendon of a pennate muscle when the tension in the fibers is 100 N, given the following angles of pennation?

1. 40°
2. 60°
3. 80°

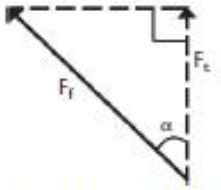
Known

$$F_{fibers} = 100 \text{ N}$$

angle of pennation = 40°, 60°, 80°

Solution

Wanted: F_{tendon}



The relationship between the tension in the fibers and the tension in the tendon is

$$F_{tendon} = F_{fibers} \cos \alpha$$

1. For $\alpha = 40°$, $F_{tendon} = (100 \text{ N})(\cos 40)$

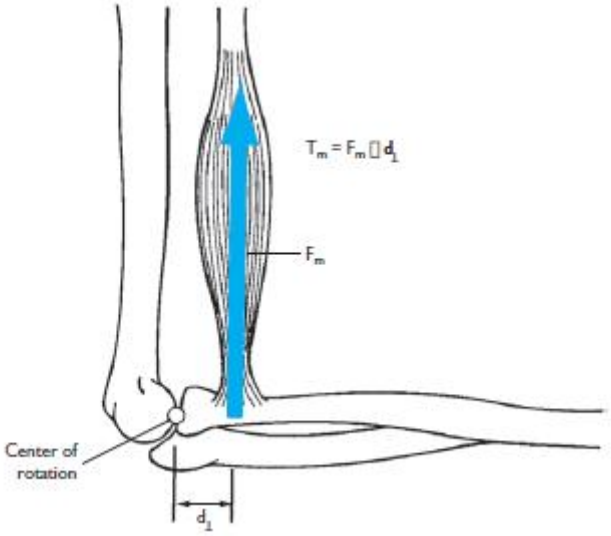
   $F_{tendon} = 76.6 \text{ N}$

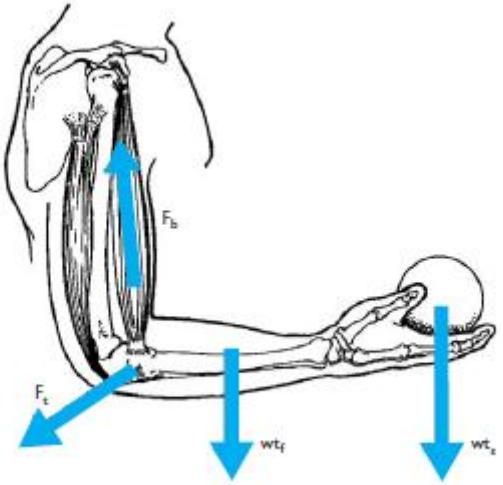
2. For $\alpha = 60°$, $F_{tendon} = (100 \text{ N})(\cos 60)$

   $F_{tendon} = 50 \text{ N}$

3. For $\alpha = 80°$, $F_{tendon} = (100 \text{ N})(\cos 80)$

   $F_{tendon} = 17.4 \text{ N}$


$T_m = F_m \perp d_\perp$
F_m
Center of rotation
$d_\perp$


F_b
F_c
wt_f
wt_s

Skeletal Muscle Function

How are motor units (MUs) recruited?

- slow twitch (ST) fibers are easier to activate than fast twitch (FT) fibers
- ST fibers are always recruited first
- increasing speed, force, or duration of movement involves progressive recruitment of MUs with higher and higher activation thresholds

Skeletal Muscle Function

What terms are used to describe muscle contractions based on change in muscle length?

Åconcentric: involving shortening

Åeccentric: involving lengthening

Åisometric: involving no change

Skeletal Muscle Function

What roles are assumed by muscles?

Åagonist: acts to cause a movement
Åantagonist: acts to slow or stop a movement
Åstabilizer: acts to stabilize a body part against some other force

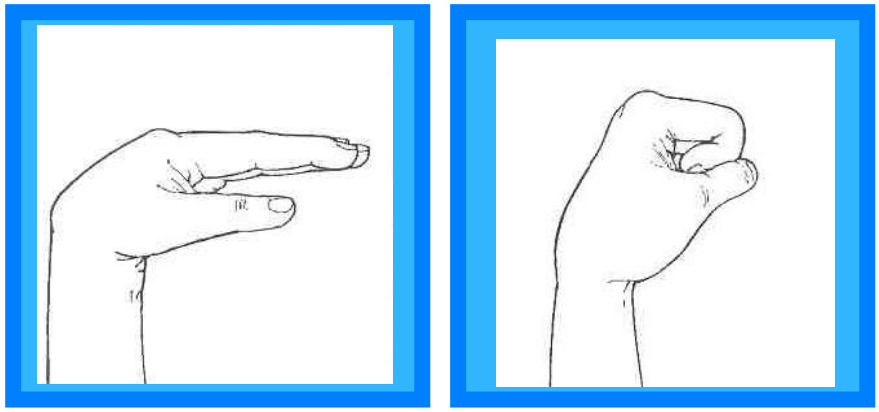
Skeletal Muscle Function

What are disadvantages associated with muscles that cross more than one joint?

Åactive insufficiency: failure to produce force when slack

Åpassive insufficiency: restriction of joint range of motion when fully stretched

Skeletal Muscle Function



active insufficiency: failure to produce force when muscles are slack (decreased ability to form a fist with the wrist in flexion)

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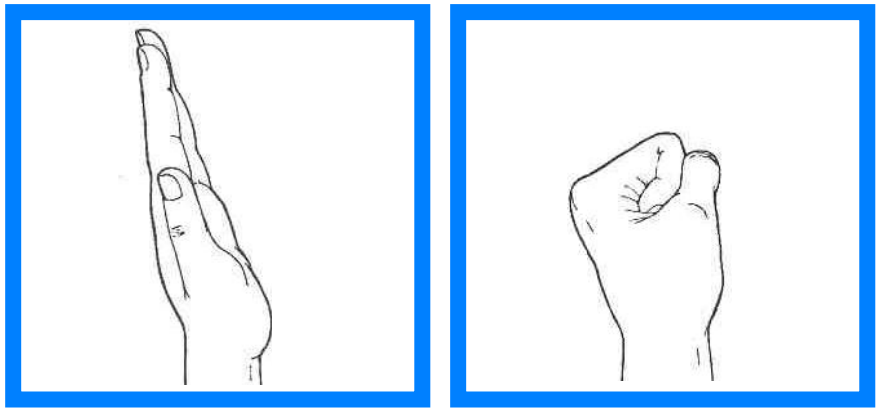
Skeletal Muscle Function



passive insufficiency: restriction of joint range of motion when muscles are fully stretched (decreased ROM for wrist extension with the fingers extended)

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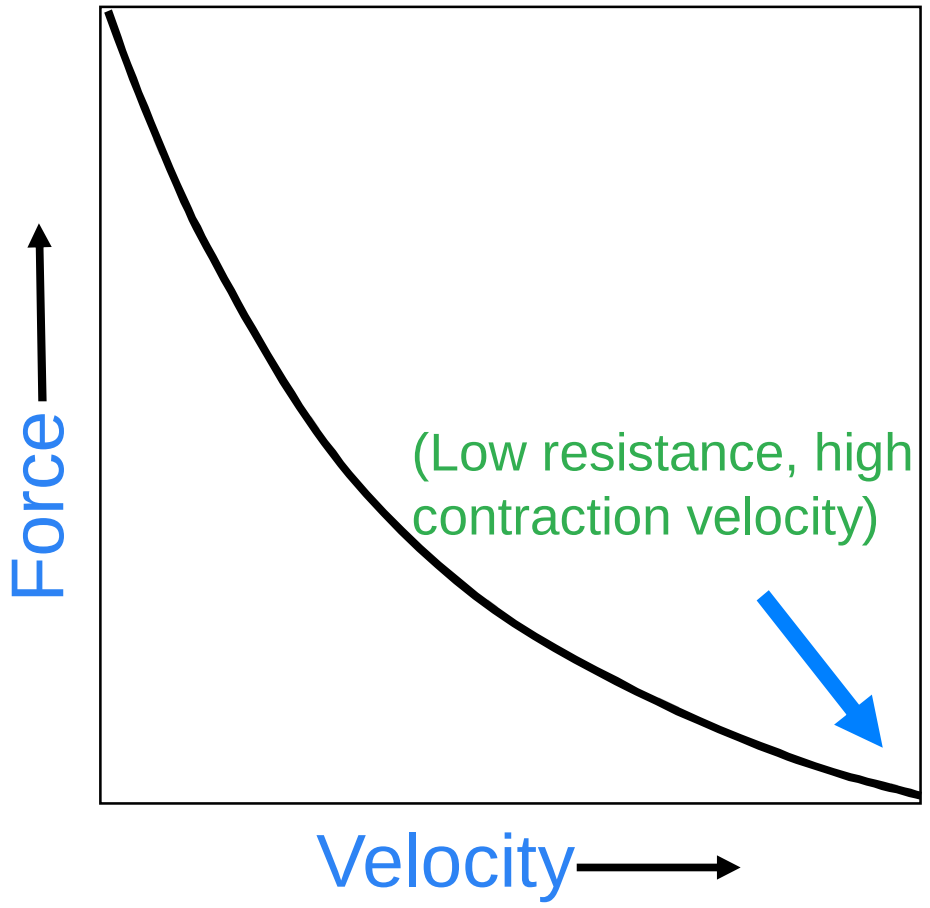
Factors Affecting Muscular Force Generation

The force-velocity relationship for muscle tissue: When resistance (force) is negligible, muscle contracts with maximal velocity.



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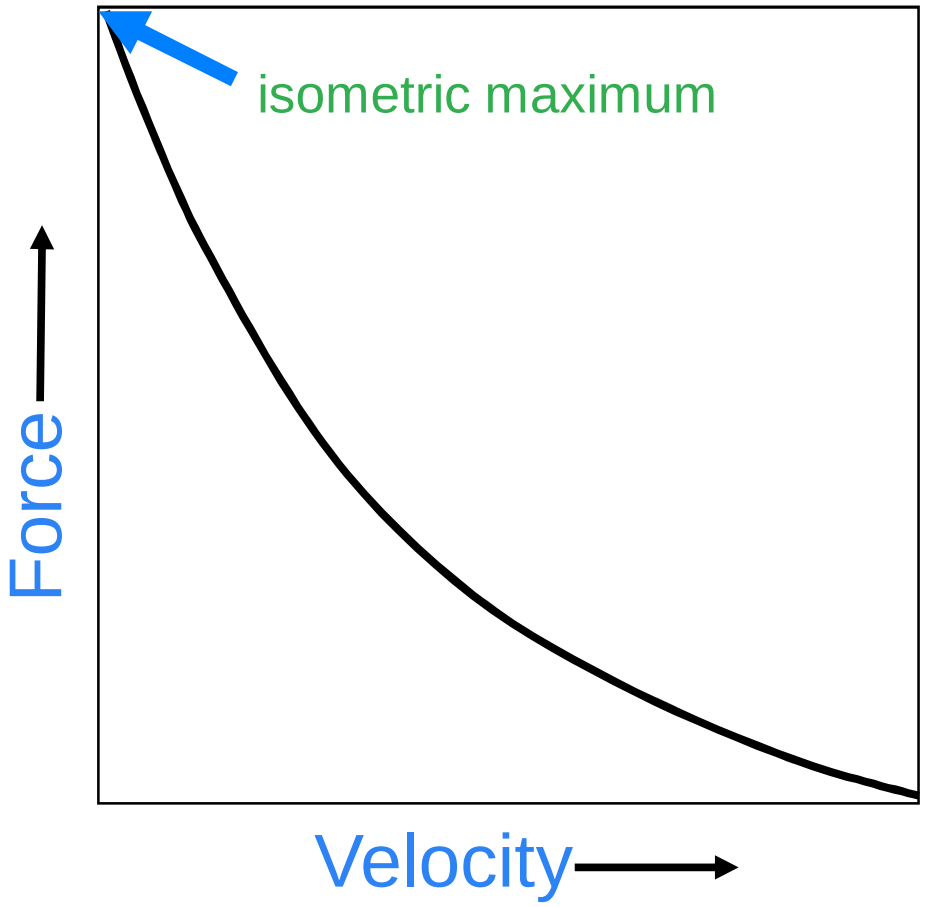
Factors Affecting Muscular Force Generation

The force-velocity relationship for muscle tissue: As the load increases, concentric contraction velocity slows to zero at isometric maximum.



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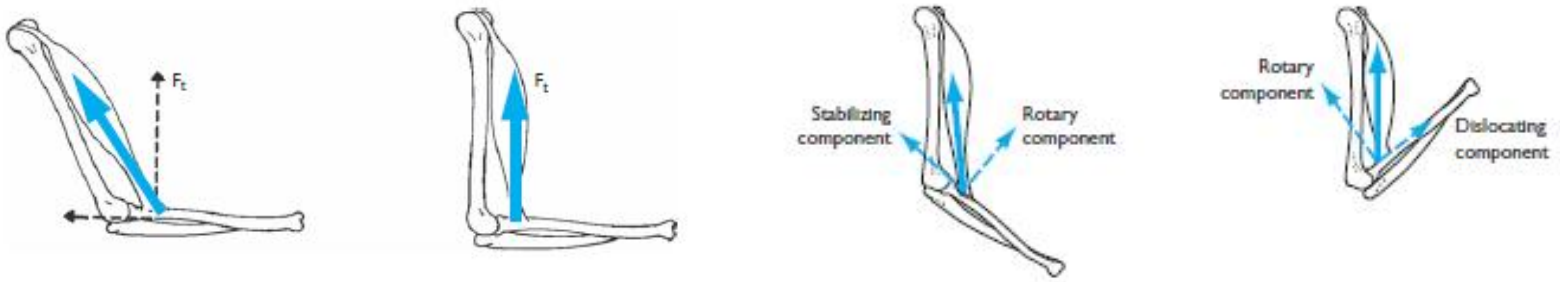
Muscular Strength, Power and Endurance

How do we measure muscular strength?

(the amount of torque a muscle group can generate at a joint)



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SAMPLE PROBLEM 6.2

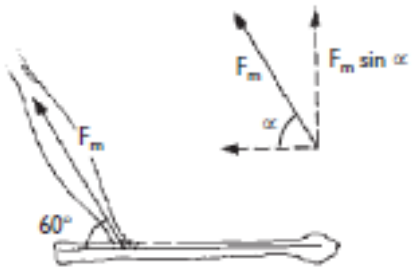
How much torque is produced at the elbow by the biceps brachii inserting at an angle of 60° on the radius when the tension in the muscle is 400 N? (Assume that the muscle attachment to the radius is 3 cm from the center of rotation at the elbow joint.)

Known

$F_m = 400$ N

$\alpha = 60°$

$d_\perp = 0.03$ m



Solution

Wanted: T_m

Only the component of muscle force perpendicular to the bone generates torque at the joint. From the diagram, the perpendicular component of muscle force is

$$F_p = F_m \sin \alpha$$
$$F_p = (400 \text{ N}) (\sin 60)$$
$$= 346.4 \text{ N}$$

$$T_m = F_p d_\perp$$
$$= (346.4 \text{ N})(0.03 \text{ m})$$

$$T_m = 10.4 \text{ N-m}$$

Muscular Strength, Power and Endurance

What factors affect muscular strength?

Åtension-generating capability of the muscle tissue, which is in turn affected by:

Åmuscle cross-sectional area

Åtraining state of muscle

SAMPLE PROBLEM 6.3

How much tension may be developed in muscles with the following cross-sectional areas?

1. $4\ cm^2$
2. $10\ cm^2$
3. $12\ cm^2$

Known

muscle cross-sectional areas = $4\ cm^2$, $10\ cm^2$, and $12\ cm^2$

Solution

Wanted: tension development capability

The tension-generating capability of muscle tissue is $90\ N/cm^2$. The force produced by a muscle is the product of $90\ N/cm^2$ and the muscle's cross-sectional area. So,

1. $F = (90\ N/cm^2)\,(4\ cm^2)$

   $F = 360\ N$

2. $F = (90\ N/cm^2)\,(10\ cm^2)$

   $F = 900\ N$

3. $F = (90\ N/cm^2)\,(12\ cm^2)$

   $F = 1080\ N$

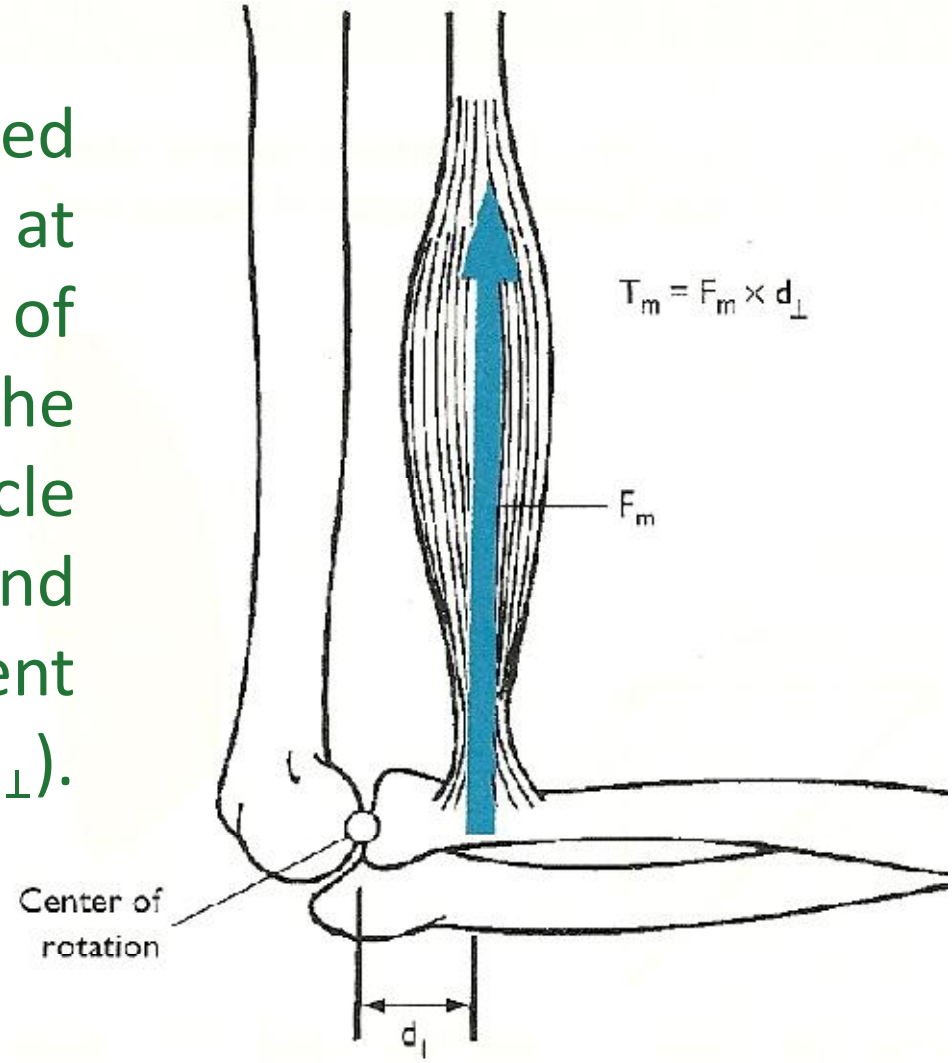
Muscular Strength, Power and Endurance

What factors affect muscular strength?

- moment arms of the muscles crossing the joint (mechanical advantage), in turn affected by:
- distance between muscle attachment to bone and joint center
- angle of the muscleôs attachment to bone

Skeletal Muscle Function

Torque produced by a muscle (T_m) at the joint center of rotation is the product of muscle force (F_m) and muscle moment arm ($d_\perp$).



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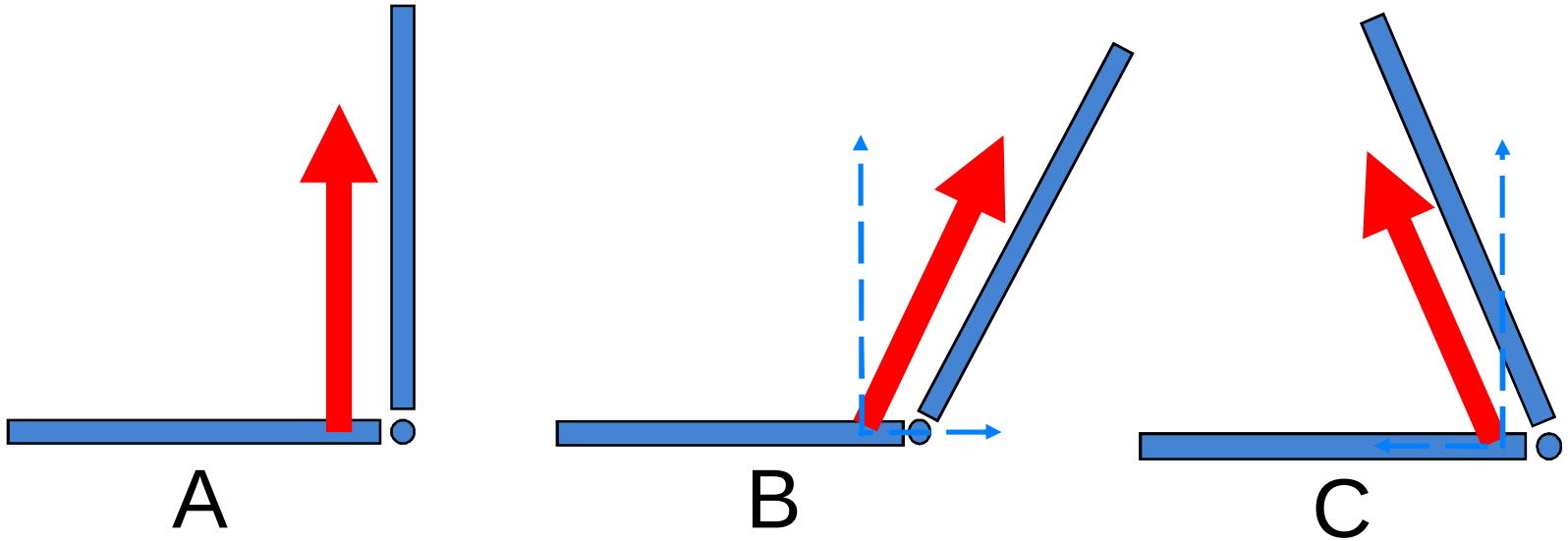
Muscular Strength, Power and Endurance



The mechanical advantage of the biceps bracchi is maximum when the elbow is at approximately 90 degrees (A), because 100% of muscle force is acting to rotate the radius. As the joint angle increases (B) or decreases (C) from 90 degrees, the mechanical advantage of the muscle is lessened because more and more of the force is pulling the radius toward or away from the elbow rather than contributing to forearm rotation.

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Muscular Strength, Power and Endurance

What is muscular power?

- the product of muscular force and the velocity of muscle shortening
- the rate of torque production at a joint
- the product of net torque and angular velocity at a joint

Muscular Strength, Power and Endurance

What is muscular endurance?

Åthe ability of muscle to exert tension over a period of time