

# NEUROMUSCULAR ADAPTATIONS TO RESISTANCE TRAINING


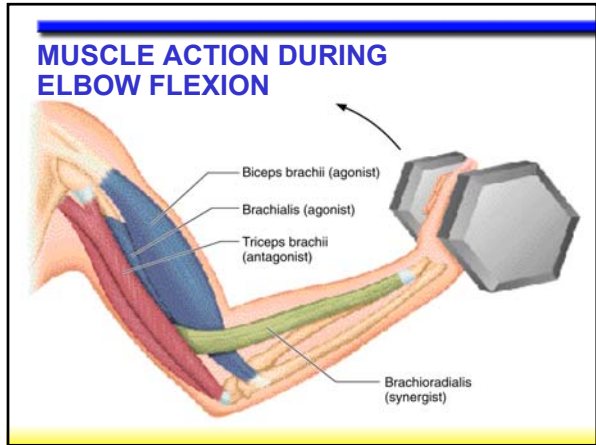


## Functional Classification of Muscles

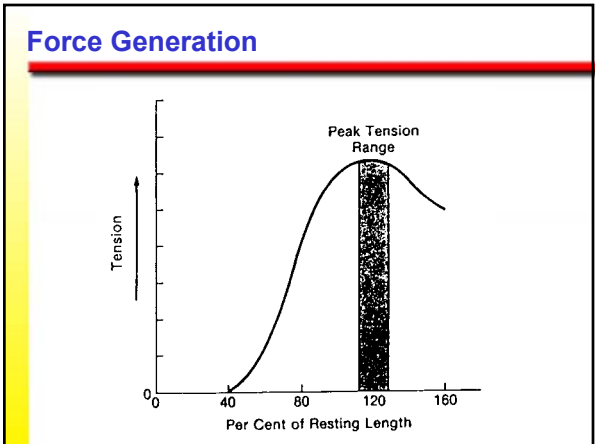
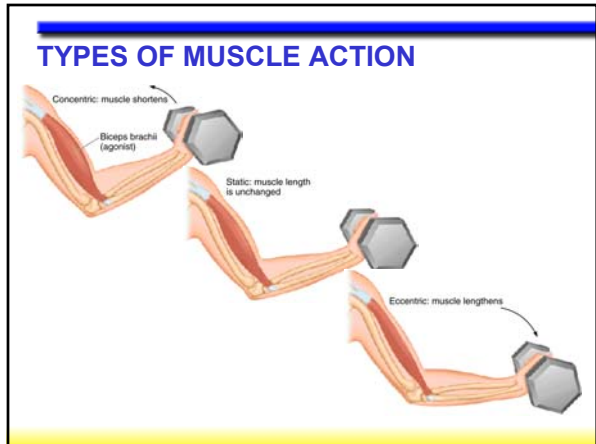
**Agonists**—prime movers; responsible for the movement

**Antagonists**—oppose the agonists to prevent overstretching of them

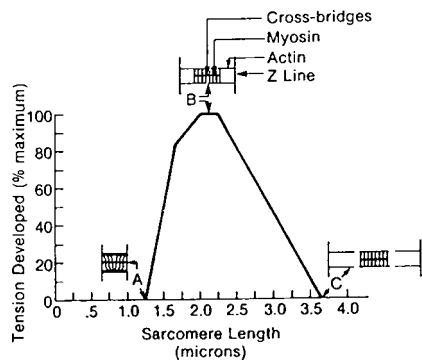
**Synergists**—assist the agonists and sometimes fine-tune the direction of movement

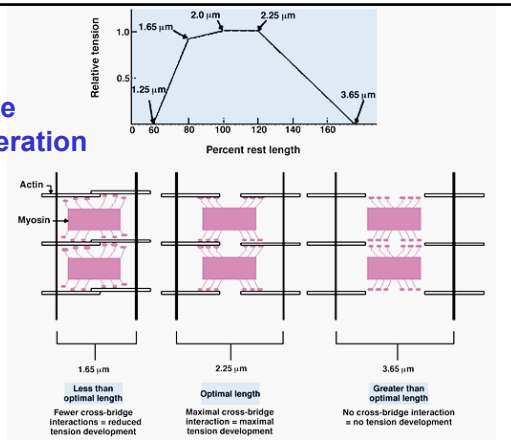
- ## Classification of Muscle Contractions
- ### Dynamic Contractions
1. Concentric – muscle develops tension while shortening
  2. Eccentric – muscle develops tension while lengthening
  3. Isotonic – muscle develops constant tension while shortening
  4. Isokinetic – muscle develops maximum tension while shortening at a constant velocity
- ### Static Contractions
1. Isometric – muscle develops tension without shortening



## Force Generation

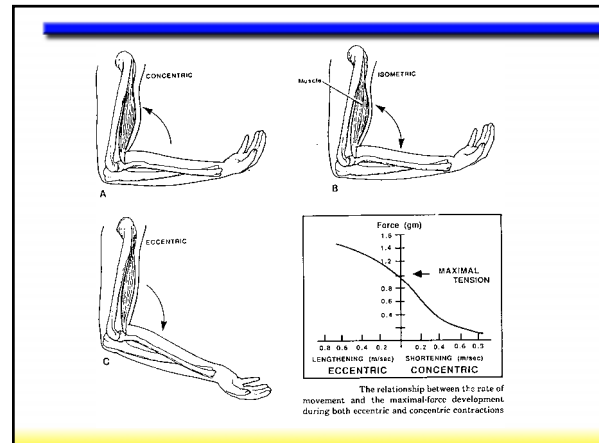


## Force Generation

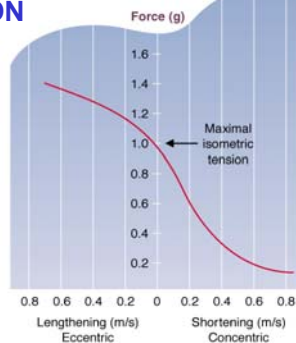


## Factors Influencing Force Generation

- Number of motor units activated
- Type of motor units activated (FT or ST)
- Muscle size
- Initial muscle length
- Joint angle
- Speed of muscle action (shortening or lengthening)

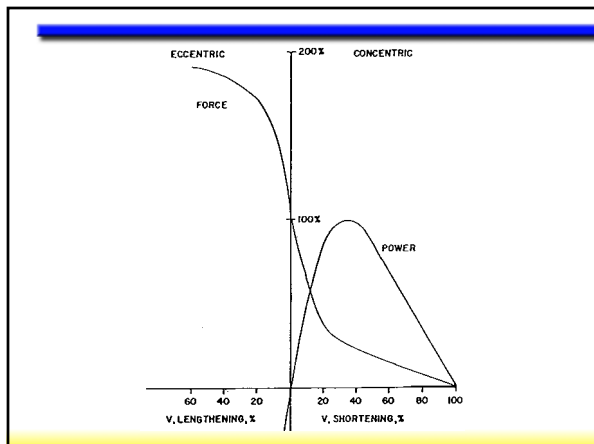
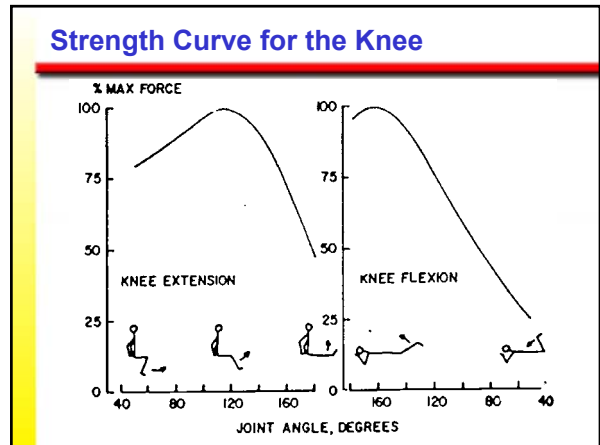
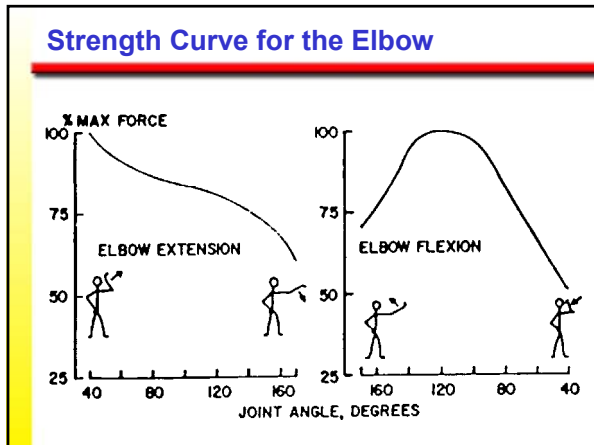
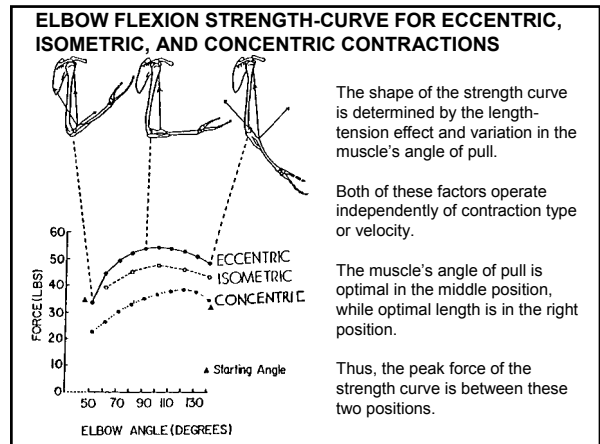
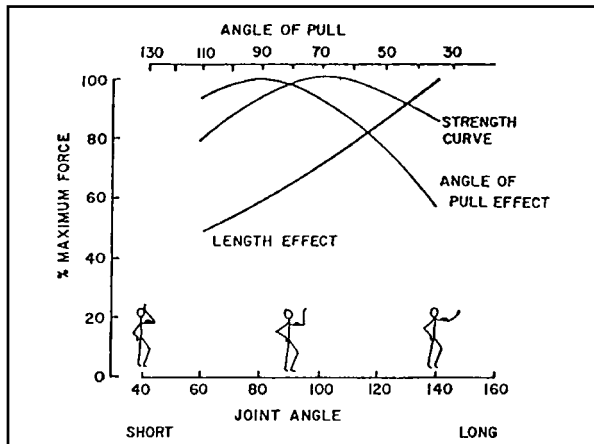


## MUSCLE LENGTH vs FORCE PRODUCTION



## Effect of muscle length and angle of pull upon elbow flexion strength

The length-tension effect and the angle of pull effect interact to produce the strength curve for elbow flexion. Through the range of movement depicted, the length effect acts to increase muscle tension from the shortest to longest muscle lengths. The longest length corresponds to an elbow joint angle (bottom horizontal axis) of 140°. In contrast the optimum angle of pull (90°, see top horizontal axis) occurs at a joint angle of about 80°. Thus, the peak of the resultant strength curve would be expected to occur somewhere between joint angles of 80° and 140°; in fact, it occurs at a joint angle of about 100°.



**Key Points**

**Use of Muscles**

- Muscles involved in movement can be classified as agonists, antagonists, and synergists.
- Three types of muscle action are concentric, static, and eccentric.
- Force production is increased by recruiting more motor units.

*(continued)*

## Key Points

### Use of Muscles

- All joints have an optimal angle at which the muscles crossing the joint produce maximal force.
- The angle of maximal force depends on the relative position of the muscle's insertion on the bone and the load placed on the muscle.
- Speed of action affects the amount of force produced.

## Measuring Muscular Performance

**Strength**—the maximal force a muscle or muscle group can generate.

**Speed**—the maximal rate of movement or velocity that a muscle or muscle group can generate.

**Power**—the product of strength and the speed of movement.

**Muscular endurance**—the capacity to sustain repeated muscle actions.



## One-Repetition Maximum (1-RM)

The maximal weight an individual can lift just once.



## Power

- The functional application of strength and speed
- The key component of many athletic performances
- Work = force x distance e.g. 1 Joule = 1 newton-meter, (i.e. a force of 1 newton (9.81 kg) applied through a distance of 1 meter)
- Power = (force x distance)/time or work per unit of time (i.e. 1 Watt = 1 Joule/second)



## Muscular Endurance

- Can be evaluated by noting the number of repetitions you can perform at a given percentage of your 1-RM
- Is increased through gains in muscular strength
- Is increased through changes in local metabolic and circulatory function



## Key Points

### Terminology

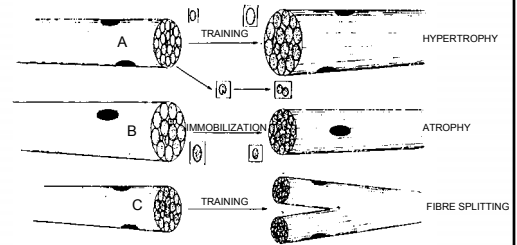
- Muscular strength is the maximal amount of force a muscle or group of muscles can generate.
- Muscular power is the product of strength and speed of the movement.
- Though two individuals can lift the same amount of weight, if one can lift it faster, she is generating more power than the other.
- Muscular endurance is the ability of a muscle to sustain repeated muscle actions or a single static action.

## Muscle Size

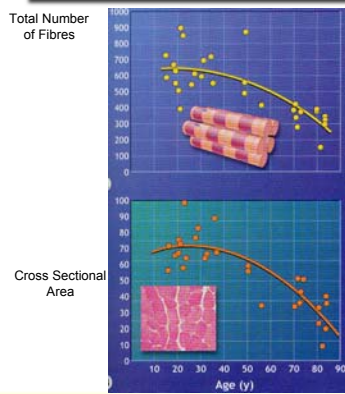
- ♦ **Hypertrophy** refers to increases in muscle size.
- ♦ **Atrophy** refers to decreases in muscle size.
- ♦ Muscle strength involves more than just muscle size.



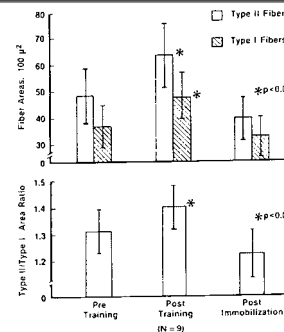
## Morphological Changes in Skeletal Muscle



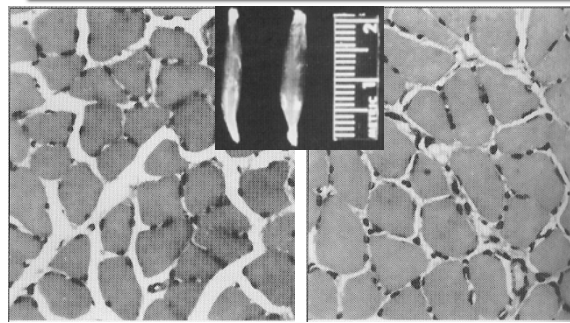
A possible model for the changes in muscle size that occur in response to strength training and immobilization. A. With training, cross-sectional fiber area increases in direct proportion to the increase in myofibril size and number. B. With immobilization fiber area decreases in direct proportion to the decrease in myofibril area. C. The possibility of training induced fiber splitting.



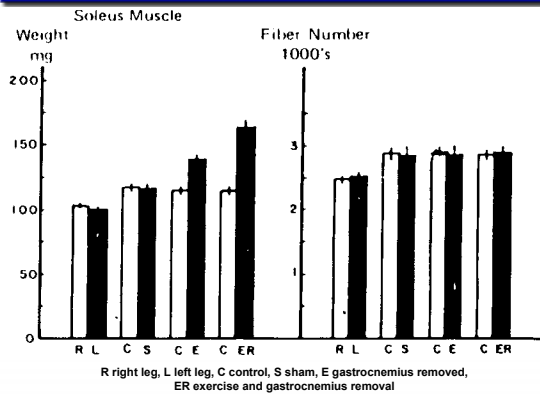
Relationship between age in years and the total number of muscle fibres and the cross sectional area of muscle. Muscle size begins to decrease after approximately 30 years of age, decreasing 10% by age 50 and at a much faster rate thereafter.

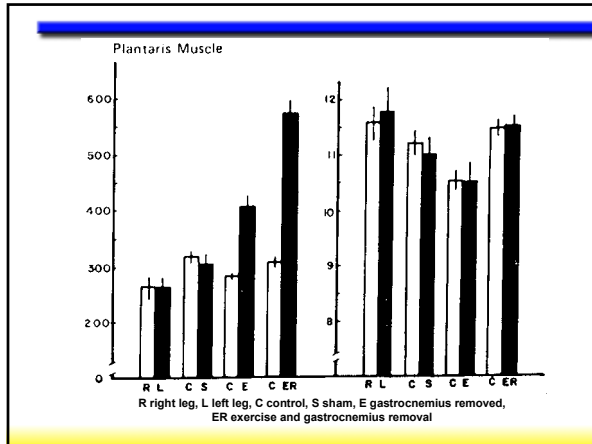


Cross sectional area for Type I and Type II fibers in the control condition and following training and immobilization. The lower figure illustrates this data as Type II/Type I area ratios. Values are means  $\pm$  1SD.



Diameter of hypertrophied muscle was 24-34% greater than control and the number of nuclei was 40-52% greater 5 days following gastrocnemius tentotomy





## Muscle Hypertrophy

**Transient**—pumping up of muscle during a single exercise bout due to fluid accumulation from the blood plasma into the interstitial spaces of the muscle.

**Chronic**—increase of muscle size after long-term resistance training due to changes in muscle fiber number (fiber hyperplasia) or muscle fiber size (fiber hypertrophy).

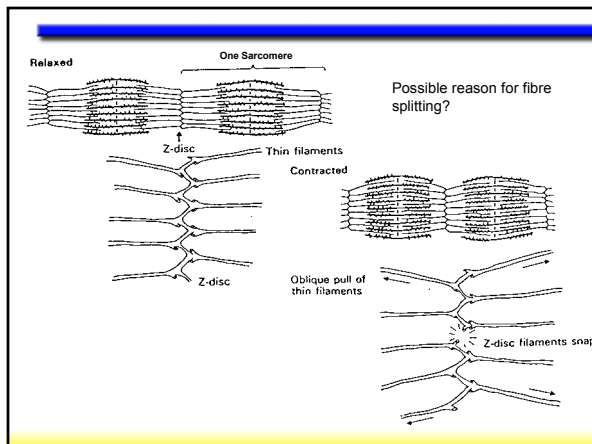


## Fiber Hypertrophy

- The numbers of myofibrils and actin and myosin filaments increase, resulting in more cross-bridges.
- Muscle protein synthesis increases during the post exercise period.
- Testosterone plays a role in promoting muscle growth.
- Training at higher intensities appears to cause greater fiber hypertrophy than training at lower intensities.

## Fiber Hyperplasia

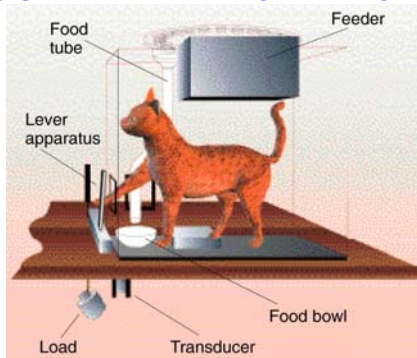
- Muscle fibers split in half with intense weight training.
- Each half then increases to the size of the parent fiber.
- Satellite cells may also be involved in skeletal muscle fiber generation.
- It has been clearly shown to occur in animal models; only a few studies show this occurs in humans too.



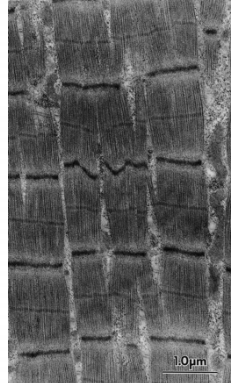
## SPLITTING MUSCLE FIBER



## RESISTANCE TRAINING IN CATS



Roth, Stephen M., Gregory F. Martel, Frederick M. Ivey, Jeffrey T. Lemmer, Brian L. Tracy, Diane E. Hurlbut, E. Jeffrey Metter, Ben F. Hurley, and Marc A. Rogers. Ultrastructural muscle damage in young vs. older men after high volume, heavy-resistance strength training. *J. Appl. Physiol.* 86(6): 1833–1840, 1999.



Electron micrograph of a skeletal muscle fiber exhibiting Z-line streaming and myofibrillar splitting without associated myofibril disruption (magnification  $\times 16,000$ ).

Kelley, George. Mechanical overload and skeletal muscle fiber hyperplasia: a meta-analysis. *J. Appl. Physiol.* 81(4): 1584–1588, 1996.

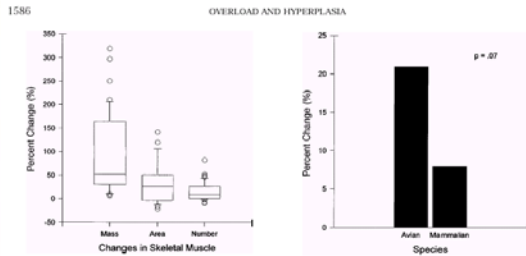


Fig. 1. Percent changes in skeletal muscle mass ( $n = 37$ ), fiber area ( $n = 23$ ), and fiber number ( $n = 37$ ).  $\square$ , Outliers beyond 15th and 95th percentiles. Percent change calculated as (treatment - control)/treatment  $\times 100$ .

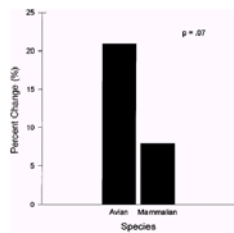


Fig. 3. Percent increases in muscle fiber number according to whether species was avian ( $n = 20$ ) or mammalian ( $n = 17$ ). Percent change calculated as (treatment - control)/treatment  $\times 100$ .

Kelley, George. Mechanical overload and skeletal muscle fiber hyperplasia: a meta-analysis. *J. Appl. Physiol.* 81(4): 1584–1588, 1996.

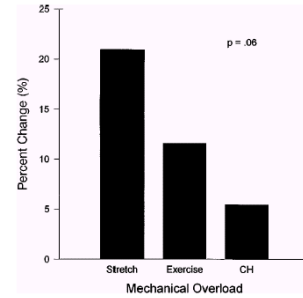
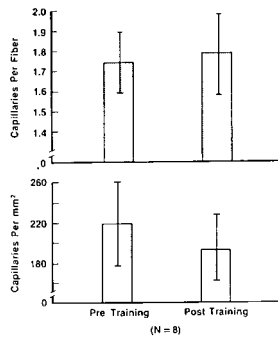


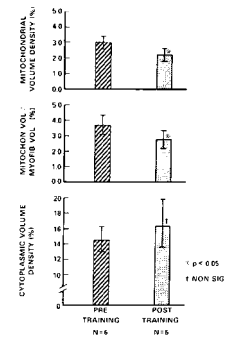
Fig. 4. Percent increases in muscle fiber number according to whether mechanical overload consisted of stretch ( $n = 20$ ), compensatory hypertrophy (CH;  $n = 10$ ), or exercise ( $n = 7$ ). Percent change calculated as (treatment - control)/treatment  $\times 100$ .

## Muscle Capillary Changes with Resistance Training



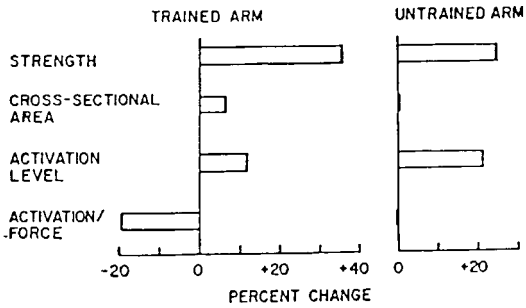
Capillary supply to biceps brachii before and after training. Values are expressed as a capillary-to-fiber ratio as well as capillary density (capillaries per  $\text{mm}^2$ ). Values are means  $\pm 1$  SD.

## Mitochondrial and Cytoplasmic Volume, Density, and Volume:Density Ratio before and after Resistance Training

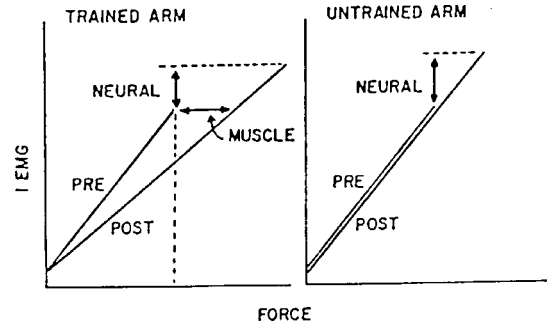


Mean  $\pm 1$  SD mitochondrial and cytoplasmic volume density and mitochondrial-to-myofibrillar volume ratio before and after training. (MacDougall et al., 1979).

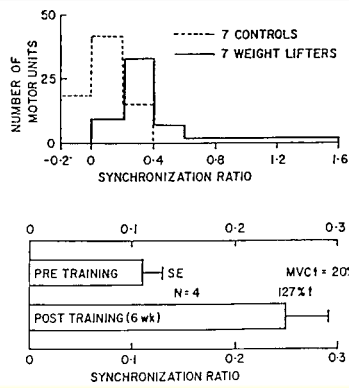
**Trained Bicep Compared to an Untrained Bicep**



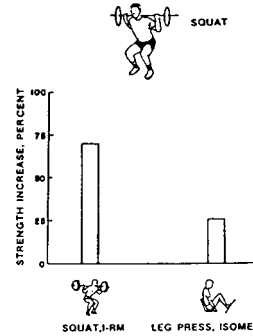
**Trained Bicep Compared to an Untrained Bicep**



**Effect of Resistance Training on the Synchronization Ratio of Motor Unit Activation**

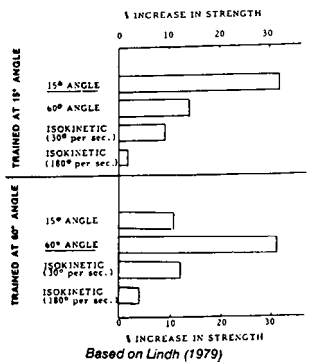


**SPECIFICITY OF STRENGTH GAINS**

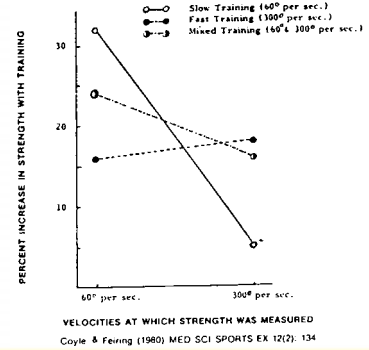


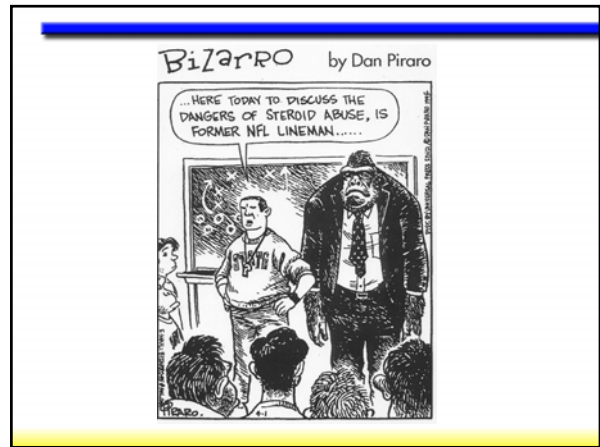
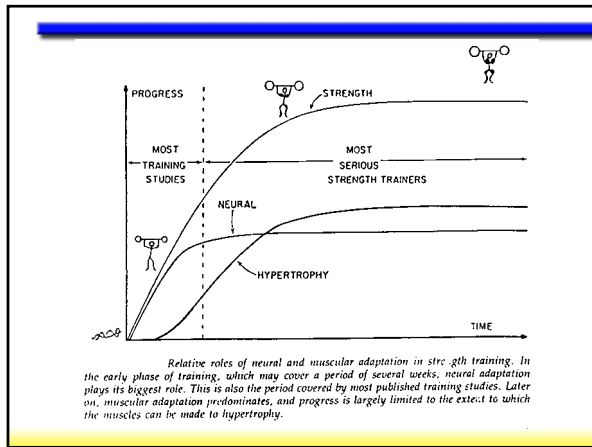
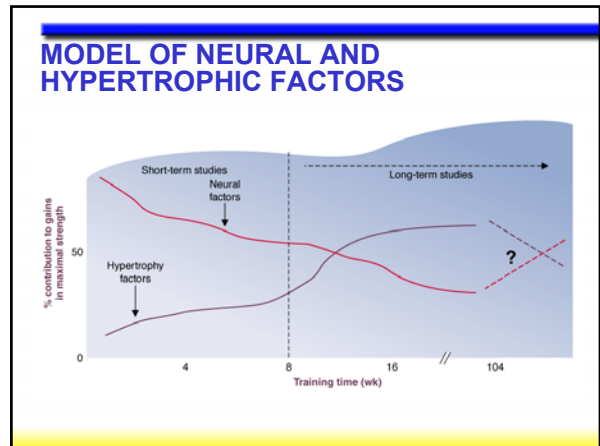
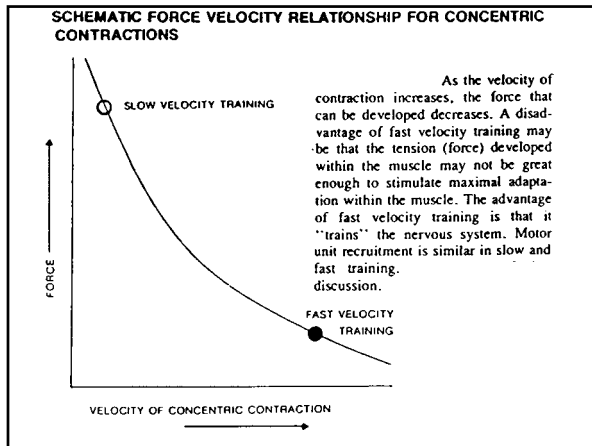
THORSTENSSON & KARLSSON (1974) ACTA PHYSIOL SCAND 91(3): 21A

**ISOMETRIC KNEE EXTENSION TRAINING**



**INTERACTION BETWEEN STRENGTH GAINS AND VELOCITY OF TRAINING**





### Results of Resistance Training

- ◆ Increased muscle size (hypertrophy).
- ◆ Alterations of neural control of trained muscle.
- ◆ Studies show strength gains can be achieved without changes in muscle size, but not without neural adaptations.

### Physiological Adaptations That Occur in Response to Resistance Training

System/Variable	Response	System/Variable	Response
<b>Muscle Fibers</b>		<b>Intramuscular Fuel Stores</b>	
Number	Not known	Adenosine triphosphate	Increase
Size	Increase	Phosphocreatine	Increase
		Glycogen	Increase
		Triglycerides	Not known
<b>Capillary Density</b>		<b>VO<sub>2</sub> max (ml·kg<sup>-1</sup>·min<sup>-1</sup>)</b>	
In bodybuilders	No change	Circuit weight training	Increase
In power lifters	Decrease	Heavy resistance training	No change
<b>Mitochondrial Volume Density</b>	Decrease		
		<b>Connective Tissue</b>	
<b>Enzymes</b>		Ligament strength	Increase
Creatine phosphokinase	Increase	Tendon strength	Increase
Myokinase	Increase	Collagen content of muscle	No change
		<b>Bone</b>	
<b>Enzymes of Glycolysis</b>		Mineral content	Increase
Phosphofructokinase	Increase	Cross-sectional area	No change
Lactate dehydrogenase	No change		
<b>Aerobic Metabolism Enzymes</b>			
Carbohydrate metabolism	Increase		
Triglycerides	Not known		

### Key Points

#### Resistance Training

- Neural adaptations always accompany strength gains from resistance training; hypertrophy may or may not be present.
- Transient hypertrophy results from short-term increases in muscle size due to fluid in the muscle.
- Chronic muscle hypertrophy results from long-term training and is caused by structural changes in the muscle.

(continued)

### Key Points

#### Resistance Training

- Muscle hypertrophy is most clearly due to increases in fiber size, but also may be due to increases in the number of fibers.
- Muscle atrophy occurs when muscles are inactive; however, a planned reduction in training can maintain muscle size and strength for a period of time.
- A muscle fiber type can take on characteristics of the opposite type in response to training. Cross-innervation or chronic stimulation of fibers may convert one fiber type into another fiber type.