Mechanical Muscles

Objectives:

• Physiological optimalization of muscle performance.
• Length-tension relationship.
• Force-velocity relationship.
• Preload and afterload.
• Effects of muscle fiber characteristics on muscle performance.

Force produced in skeletal muscles is related to the number of motor units recruited for the task. Often, there are muscle fibers that are not recruited for the working muscles. They become the load of the working fibers.
Muscle fiber contraction does not produce immediate movement of bones until the non-contractile muscle fibers also move together. Similarly, muscle contraction does not produce movement if the tendons are not fully stretched. The two elastic forces are added to the muscle fiber in parallel and in series, respectively.

**Optimal conditions**

- The smaller parallel elastic force (or the greater elasticity) the better.
- The larger series elastic force (or the smaller elasticity) the better.
Three mechanical functions of working muscles

- **Force** or tension that the muscle needs to produce against the load added to the muscle.
- **Length** or distance of the muscle shortening.
- **Velocity** or speed of the muscle movement.
Isometric Contraction

Isotonic Contraction
Muscle contraction

- Isometric contraction: steady.
- Isotonic contraction: dynamic.
Length-tension relationship in skeletal muscles
Length-tension relationship in cardiac muscles

Length-tension relationship in smooth muscles
FIGURE 12-25
Effects on stroke volume of stimulating the sympathetic nerves to the heart. Stroke volume is increased at any given end-diastolic volume; that is, the sympathetic stimulation has increased ventricular contractility.
Length-tension relationship

- The length-tension relationship is useful to understand the force produced by muscles with load added to the muscles before contraction.
- The relationship indicates that an increase in muscle length or preload can improve muscle performance.
- The muscle stretch has a limitation, beyond which the muscle performance declines rapidly.
FIGURE 11-27
Velocity of skeletal-muscle fiber shortening and lengthening as a function of load. Note that the force being sustained by cross bridges during a lengthening contraction is greater than the maximum isometric tension.

Mechanics
FIGURE 12-26
Effects of sympathetic stimulation on ventricular contraction and relaxation. Note that both the rate of force development and the rate of relaxation are increased, as is the maximal force developed. All these changes reflect an increased contractility.
FV or load-velocity relationship

• The FV relationship is useful to understand the speed that muscles develop with a fixed load during the muscle contraction.
• The relationship shows that the maximum velocity ($V_0$) is achieved with no afterload.
• The velocity decreases with an increase in the afterload.
• The velocity becomes zero at a point when the muscle can no longer move the load, or the force is equal to the load ($F_0$).
• Further increase in the load does not produce immediate elongation of the muscle until the afterload > 1.6 times of the $F_0$.

Isometric and isotonic contraction

• Isometric contraction preparation: length-tension relationship,
• Isotonic contraction preparation: force-velocity relationship.
Serial cross sections of human deltoid muscle stained for myofibrillar ATPase (mATPase) after preincubation at pH 10.5 or 4.3, cytochrome c oxidase (Cyt C ox), and α-glycerophosphatase dehydrogenase (α-glyc), respectively. The fiber types are indicated; for IIB (IIx) fibers, see text. They show a largely reciprocal staining pattern after acid and alkaline preincubation, respectively, as well as in the reaction for cytochrome c oxidase and α-glycerophosphatase dehydrogenase, respectively. The plate illustrates the establishment of morphological fiber typing. Original magnification, ×95.

I, slow fiber; IIB (IIx), fast glycolytic fiber; IIA and IIC, fast oxidative fiber.
FIGURE 9.29
The use of fatigue development in the three fiber types. Each line shows the contractile response to a brief tetanic stimulus and relaxation. The contractile responses occurring between about 9 min and 60 min are not shown on the figure.

<table>
<thead>
<tr>
<th>Primary source of ATP production</th>
<th>Oxidative phosphorylation</th>
<th>Oxidative phosphorylation</th>
<th>Gluconeogenesis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mitochondria</td>
<td>Many</td>
<td>Many</td>
<td>Few</td>
</tr>
<tr>
<td>Capillaries</td>
<td>Many</td>
<td>Many</td>
<td>Few</td>
</tr>
<tr>
<td>Myoglobin content</td>
<td>High (red muscle)</td>
<td>High (red muscle)</td>
<td>Low (white muscle)</td>
</tr>
<tr>
<td>Glycolytic enzyme activity</td>
<td>Low</td>
<td>Intermediate</td>
<td>High</td>
</tr>
<tr>
<td>Glycogen content</td>
<td>Low</td>
<td>Intermediate</td>
<td>High</td>
</tr>
<tr>
<td>Rate of fatigue</td>
<td>Slow</td>
<td>Intermediate</td>
<td>Fast</td>
</tr>
<tr>
<td>Myosin-ATPase activity</td>
<td>Low</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>Contraction velocity</td>
<td>Slow</td>
<td>Fast</td>
<td>Fast</td>
</tr>
<tr>
<td>Fiber diameter</td>
<td>Small</td>
<td>Intermediate</td>
<td>Large</td>
</tr>
<tr>
<td>Motor unit size</td>
<td>Small</td>
<td>Intermediate</td>
<td>Large</td>
</tr>
<tr>
<td>Size of motor neuron innervating fiber</td>
<td>Small</td>
<td>Intermediate</td>
<td>Large</td>
</tr>
</tbody>
</table>
Characteristics of muscle cells

- Slow-oxidative fiber: weak in contraction, high in oxidative enzyme activity, rich in blood supplies, resistant to fatigue.
- Fast-glycolytic fiber: fast contraction, fast fatigue, good glycolytic activity, good glycogen storage, poor blood supplies, low oxidative enzyme activity.
- Fast-oxidative fibers: intermediate between above with contraction more like fast fiber and metabolism more like slow fiber.

Impact of exercise

- Muscles fibers can undergo hypertrophy and atrophy depending on more and less exercise.
- The best physical exercise should impact multiple systems besides muscles.
- Exercise has little benefit to the body if it trains muscles alone.
- Many sport games should not be considered as physical exercise for regular people.
Muscle Training

- Training does not increase number of muscle fibers.
- Training increases the muscle mass and function.
- The increase in the muscle mass is more obvious in fast-glycolytic fibers.
- Functional improvement is more obvious in slow-oxidative fibers with training.

What happens to the muscle with training?

- The proportion of different types of fibers can change in the muscle.
- When the fiber size increases, muscle mass becomes larger.
- Training does not change fiber types across groups.
- Within the type II group, training can change fibers from IIB to IIA, vice versa.
How does different training affect muscle fibers?

- Slow oxidative fiber: Low force and long time training.
- Fast glycolytic fiber: High force and short time training.
- Fast oxidative fiber: High force and long-lasting training.

Aerobic vs anaerobic exercise

- Determined by energy sources used for exercise.
- Low force and long-lasting training: aerobic.
- High force and brief training: anaerobic.
Systemic benefits

- Anaerobic exercise trains muscle strength, muscle mass, and glycogen storage in muscle fibers with modest effects on other systems.
- Aerobic exercise trains multiple systems including cardiovascular, respiratory, endocrine, metabolic and nervous systems, in addition to the muscles.
- Regular daily physical activity belongs to aerobic exercise.
Selective training of muscle fibers

- Such a practice should not be emphasized for ordinary people.
- Anaerobic training benefits the muscle force performance without much beneficial effects on other systems in the body.
- Excessive aerobic training benefits the system in the cost of potential wearing down of joints and short tissues around joints.
- Anabolic steroids increase the protein content in skeletal muscles with adverse side-effects on multiple systems.