Chapter 31:
Adaptations to Resistance Training

Adaptations are related to the principle of specificity and are dictated by the type of workouts used to address program goals and requirements of the individual.

Responses versus adaptations

- \textit{Training} is typically thought of as repeated and systematic exposure of the body to an exercise stimulus. Some adaptations take place within one or two workouts.

- \textit{Response} is the human body’s acute change in physiologic function to the stress of resistance exercise.

- \textit{Adaptation} is the quantification of consistent individual responses to the stress of resistance exercise.
<table>
<thead>
<tr>
<th>ADAPTATION</th>
<th>SIGNIFICANCE</th>
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<tbody>
<tr>
<td><strong>Performance Adaptations</strong></td>
<td></td>
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<tr>
<td>↑ Muscle strength</td>
<td>↑ Performance</td>
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<tr>
<td>↑ Muscle power</td>
<td></td>
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<tr>
<td>↑ Balance and coordination</td>
<td></td>
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<tr>
<td>↑, ↔ Flexibility</td>
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<tr>
<td>↑ Lean tissue mass</td>
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<tr>
<td>↑ Muscle endurance</td>
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<tr>
<td>↑ Motor performance</td>
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<tr>
<td>↑, ↔ VO$_{2\text{max}}$</td>
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<tr>
<td><strong>Health and Fitness Adaptations</strong></td>
<td></td>
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<tr>
<td>↓ Percent body fat</td>
<td>↑ Health and wellness</td>
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<tr>
<td>↑ Insulin sensitivity</td>
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<tr>
<td>↓ Insulin concentrations and response to glucose challenge</td>
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<tr>
<td>↓ Sarcopenia and osteoporosis</td>
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<tr>
<td>↓ Low back pain</td>
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<tr>
<td>↑ Basal metabolic rate</td>
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</tbody>
</table>

↑, increase; ↓, decrease; ↔, no change; RE, resistance exercise; ATP-CP, adenosine triphosphate-creatine phosphaste; CP, creatine phosphate; VO$_{2\text{max}}$, maximal oxygen consumption.
Resistance training may elicit adaptations along the neuromuscular chain, initiating in the higher brain centers and continuing down to the level of individual muscle fibers.

**Early phase adaptations**
- Neural factors predominate for increases in strength and power in the initial 4 to 8 weeks of training.

**Late phase adaptations**
- Increases in muscle fiber size via muscle protein accretion are responsible for most adaptation after 4 to 8 weeks of training.
Theoretical Interplay of Neural Factors and Hypertrophic Factors over Time with Resistance Training
• Muscle fiber types and adaptations
  – Major fiber types in humans:
    • Type I (slow twitch)
    • Type II (fast twitch)
  – Each muscle fiber type has subtypes: types IC, IIC, IIAC, IIA, IIAX, and IIX
  – Heavy resistance training (i.e., loads 80%–85% of the 1-RM) is needed to activate high-threshold motor units (IIX).
  – Resistance training results in transition in the percentage distribution from type IIX to IIA with little or no movement to IIC, with concomitant changes in MHC content.
  – There are likely changes from type I to II and vice versa depending on training specificity.

• Hypertrophy vs. hyperplasia
  – Hypertrophy affects whole muscle growth with training due to increased protein synthesis and reduced breakdown.
  – Hyperplasia is demonstrated in animal models via satellite cell activation, but this has not been shown in humans to date.
Muscle Fiber Types under Different pH Incubations
• Enzymatic adaptations
  – Increased enzyme activity resulting from training leads to increased rates of ATP production.
  – Conflicting evidence of resistance training effects on skeletal muscle enzyme activity

• Muscle substrate stores
  – Anaerobic energy source substrates are enhanced with resistance training.
  – These include creatine phosphate (CP) and ATP.

• Capillary adaptations
  – Adaptations vary depending on training status/technique and population assessed.
  – Increased capillary number (capillarization) occurs in type I and II fibers, and there is no change in density with fiber hypertrophy in normal subjects.
  – Heavy resistance trainers (e.g., power lifters and bodybuilders) appear to have no change in capillarization and a decrease in density.

• Mitochondrial density
  – Appears to decrease secondary to focused resistance training
Endocrine Adaptations

- Hormones play a multitude of important regulatory roles in adaptation to resistance training.
  - The primary anabolic hormones are testosterone (T), growth hormone (GH), insulin-like growth factors (IGF), and insulin.
  - The primary catabolic hormone is cortisol.

- Hormonal adaptations governed by acute response to a workout
  - magnitude may be dependent on the force of muscle contraction, amount of muscle stimulated, volume of resistance exercise, and rest interval length


<table>
<thead>
<tr>
<th>HORMONE</th>
<th>ACUTE RESPONSE TO RE</th>
<th>CHRONIC RESTING ADAPTATIONS</th>
<th>CHRONIC CHANGES TO ACUTE RESPONSE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Testosterone</td>
<td>May ↑ or ↔; an ↑ is likely with high-intensity, high-volume programs with short rest intervals. Most critical for recovery and adaptation.</td>
<td>Typically ↔ unless there are substantial changes in volume and intensity.</td>
<td>May ↑ slightly if individual can train at higher levels.</td>
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<tr>
<td>Growth Hormone</td>
<td>↑ or ↔ with low-volume, low-intensity workouts ↑ is related to anaerobic nature of workout and to blood lactate when high-intensity and -volume programs with short rest elicit large response.</td>
<td>↔; however, overnight “bursts” may ↑ if workout is strenuous enough.</td>
<td>Acute ↑ can be higher when individuals train harder over time.</td>
</tr>
<tr>
<td>Insulin</td>
<td>↔, response related to diet or plasma volume ↓</td>
<td>↔</td>
<td>↔</td>
</tr>
<tr>
<td>IGF-1</td>
<td>Delayed response based on GH secretion patterns</td>
<td>Related to GH changes, ↔ or ↑ IGF-1 in muscle ↑</td>
<td>Related to GH</td>
</tr>
<tr>
<td>Cortisol</td>
<td>↑ or ↔ with low-volume, low-intensity workouts ↑ is related to anaerobic nature of workout when high-intensity and -volume programs with short rest elicit large response.</td>
<td>↔; ↓; may ↑ with overtraining</td>
<td>May not change</td>
</tr>
<tr>
<td>Catecholamines</td>
<td>↑ during workout and before in anticipation</td>
<td>↔</td>
<td>↔</td>
</tr>
</tbody>
</table>

↑, increase; ↓, decrease; ↔, no change; RE, resistance exercise; GH, growth hormone; IGF-1, insulin-like growth factor-1.

• Bone
  – *Sensitive to intensity, compression, strain, and strain rate*
  – *Greater muscle strength increases the mechanical stress on bone, forcing bone to adapt by increasing mass and strength.*
  – *Resistance training is effective for increasing bone mineral density (BMD) in men and women of all ages.*
  – *It appears that only high-intensity resistance training may be effective for long-term progression in BMD enhancement.*

• Cartilage, ligaments, tendons, and fascia
  – *As skeletal muscle strength increases, tendons, ligaments, cartilage, and fascia must also adapt to support greater loading.*
  – *Primary stimulus for growth of connective tissue is the mechanical forces created during resistance exercise.*
• Acute responses to resistance exercise
  – Heart rate, stroke volume, cardiac output, and blood pressure increase significantly to meet the demands of resistance exercise.
  – These responses are enhanced when a Valsalva maneuver is performed.
  – Resistance training does not affect cardiorespiratory fitness.
• Resting adaptations
  – Resistance training has little or no effect on resting heart and blood pressure.
• Chronic changes to the acute resistance exercise response
  – Resistance training reduces the cardiovascular response to an acute bout of resistance exercise of similar absolute intensity or workload.
  – It also reduces the acute increases in heart rate and blood pressure during a workout of similar level of effort.
• VO$_{2\text{max}}$
  – Resistance training does not significantly affect maximal oxygen consumption (VO$_{2\text{max}}$) in fit individuals.
  – Deconditioned individuals may have improvements in VO$_{2\text{max}}$.
  – Circuit training and high-volume, short rest period programs have been shown to improve VO$_{2\text{max}}$, but the effects are considerably less than with aerobic training.
  – Combining resistance and cardiorespiratory training may also limit the amount of strength gains achieved.
• Overload from resistance exercise causes trauma to skeletal muscle.

• The immune system responds with an inflammatory response that contains and repairs the damage, removes debris from the injured area, and affects skeletal muscle hypertrophy.

• Key substances in the immune response include:
  – Leukocytes
  – Immunoglobulins
  – Cytokines
• Delayed-onset muscle soreness (DOMS) is the pain or discomfort experienced 24 to 72 hours after resistance exercising, which subsides within 2 to 3 days.

• Includes localized pain in the exercised muscles, reduced range of motion, loss of muscle strength and power, greater muscle stiffness, and swelling.

• The extent of muscle damage depends on the intensity, volume, and type of muscle actions used and the training status of the individual.

• Several mechanisms have been proposed to explain DOMS.

• Chronic resistance training will reduce the magnitude of muscle damage, inflammatory response, and ultimately DOMS.
Resistance training elicits positive cardiovascular adaptations related to pressure overload.

Positive changes include:

- Enhanced flexibility
- Reduced percent body fat
- Increased insulin sensitivity
- Decreased basal insulin levels and insulin response to a glucose challenge
- Increased basal metabolic rate
- Attenuated muscle sarcopenia
- Reduced risk of osteoporosis, colon cancer, and low back pain
- Maintenance of long-term independence and functional capacity

Overtraining is long-term excessive frequency, volume, or intensity of training resulting in prolonged fatigue and decreased performance.

Short-term excessive training is called overreaching.

Overreaching can become overtraining if recovery is not sufficient.

Overtraining is associated with greater damage or negative physiologic alterations in the neuromuscular system and worsened performance versus the norm.

Detraining is the decrease in performance and loss of some physiologic adaptations that result from cessation of resistance training or a substantial reduction in its frequency, volume, or intensity.

Decrements may occur in as little as 2 weeks, and possibly sooner in highly strength-trained individuals, but little to no reductions may be seen in recreationally trained individuals after as much as 6 weeks.
BOX 31-1  NEUROMUSCULAR FACTORS ASSOCIATED WITH AGE-RELATED DECREASES IN STRENGTH AND POWER

- Change in resting hormone levels
- Blunted acute hormonal response to exercise
- Decrease in muscular energy substrate content
- Decrease in anaerobic enzyme concentration and activity
- Decrease in mitochondrial mass
- Denervation or death of muscle cells
- Decreased muscle mass (atrophy of muscle fibers, particularly of type II)

- Decreased ability to develop force rapidly
- Antagonistic coactivation
- Changes in ability to maximally activate a muscle
- Changes at the neuromuscular junction
- Decreased firing rate of motor units
- Decreased insulin sensitivity and tolerance

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