CHAPTER THREE

Physiology

Chapter Summary

Topics covered in this chapter:

- The Body's Sources of Energy
- Three sources of ATP Production
- Classification of Skeletal Muscle Fibres
- Neural Adaptations
- Morphological Adaptations
- Physiological Process of Muscle Size Increases

Learning Objectives

After reading this chapter, you should be able to:

- Understand the influence of neural factors, energy systems and morphological factors on resistance training.
- Describe energy measurement.
- Describe the body's energy sources.
- Describe the chemical formulas of energy production.
- Describe the Anaerobic Alactic, Anaerobic Lactic and Aerobic sources of energy production and understand their application to resistance training.
- Understand the energy production systems and their use during exercise.
- Describe the neural adaptations.
- Describe the role of a motor unit.
- Understand the difference between recruitment, firing frequency and synchronization.
- Distinguish between hypertrophy and hyperplasia.
- Explain the factors affecting muscle hypertrophy.
- Describe the physiological process of hypertrophy.
- Name and describe the characteristics of the 4 classes of muscle fibre types.
- Understand the physiological process of muscle size increases.

The Body's Sources of Energy

Forms of Energy

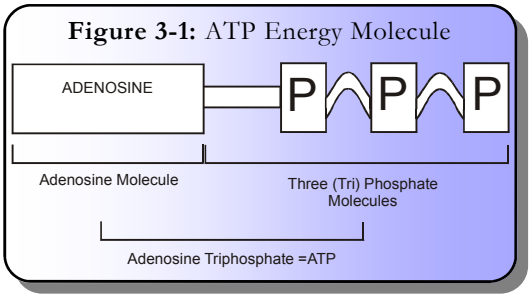
Energy exists in radiant (light and heat), chemical, electrical, mechanical, and nuclear forms. Energy, in different forms, is used to perform work. In the body, energy is needed for the maintenance of the highly organized internal systems. Maintaining the organization of the body requires constant work and, thus, constant energy. The work occurs primarily at the cellular level in the form of chemical reactions

Energy Measurement

The unit used to measure energy is the kilogram calorie (kcal also known as the calorie or cal.). A calorie is defined as the amount of heat energy required to raise one (1) kg of water one (1) degree Celsius.

The energy needed for humans to contract muscles, synthesize protein, and conduct nervous impulses is produced by a series of reactions within our cells. Without the energy, the reactions stop and the body dies.

Figure 3-1: ATP Energy Molecule

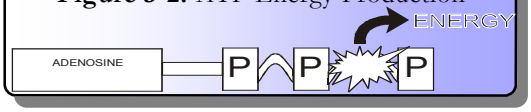


Sources of Energy

The body's energy comes from ingested food and is composed of carbohydrates, fats, and proteins. Carbohydrates and fats are the primary sources used for energy production in the body and proteins are a secondary source. Proteins are not normally used to produce energy, but are used for cellular structure and as *controllers* of chemical reactions.

In our bodies, energy from the breakdown of food is not directly used to perform work. Instead, the energy from carbohydrates and fats is used to rebuild the chemical compound adenosine triphosphate or ATP. ATP is a molecule stored within the body (Figure 3-1). Energy released during the breakdown of ATP represents an *immediate* source of energy used by cells (including muscle cells) to perform work (Figure 3-2).

Figure 3-2: ATP Energy Production

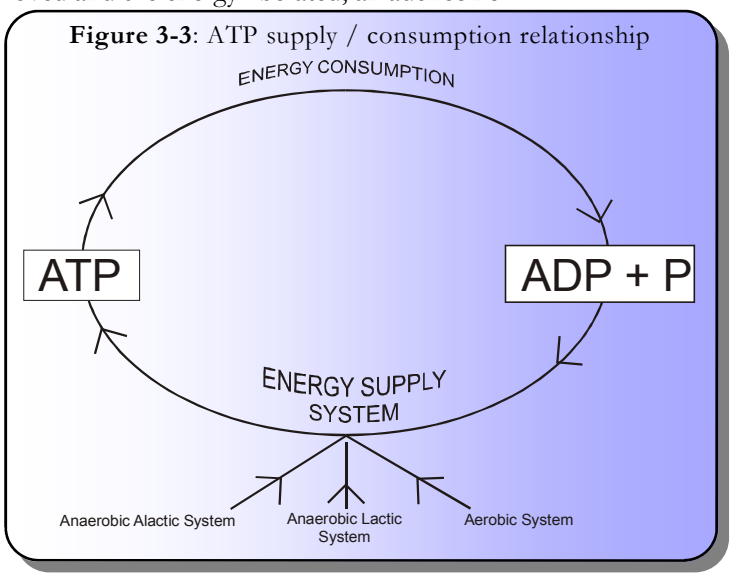


ATP Production and Storage

As Figure 3-2 illustrates, when a phosphate molecule is removed from an ATP molecule, energy is released. The released energy is used for such functions as nerve conduction and muscular contractions. Once the phosphate molecule has been removed and the energy liberated, an adenosine diphosphate (ADP) molecule remains.

ATP is stored within muscle cells in very limited quantities - long enough for a few repeated muscular contractions. If there is a demand for repeated muscular contractions, more ATP energy needs to be supplied. The regeneration of ATP requires energy that is supplied through three energy yielding systems within the muscle cell. The three energy yielding systems are the *Anaerobic Alactic* Energy Production System, *Anaerobic Lactic* Energy Production System, and the *Aerobic* Energy Production System. Figure 3-3 outlines the ATP supply and consumption relationship. If energy demand is greater than the supply, energy demand must decrease in order to balance the system.

Figure 3-3: ATP supply / consumption relationship

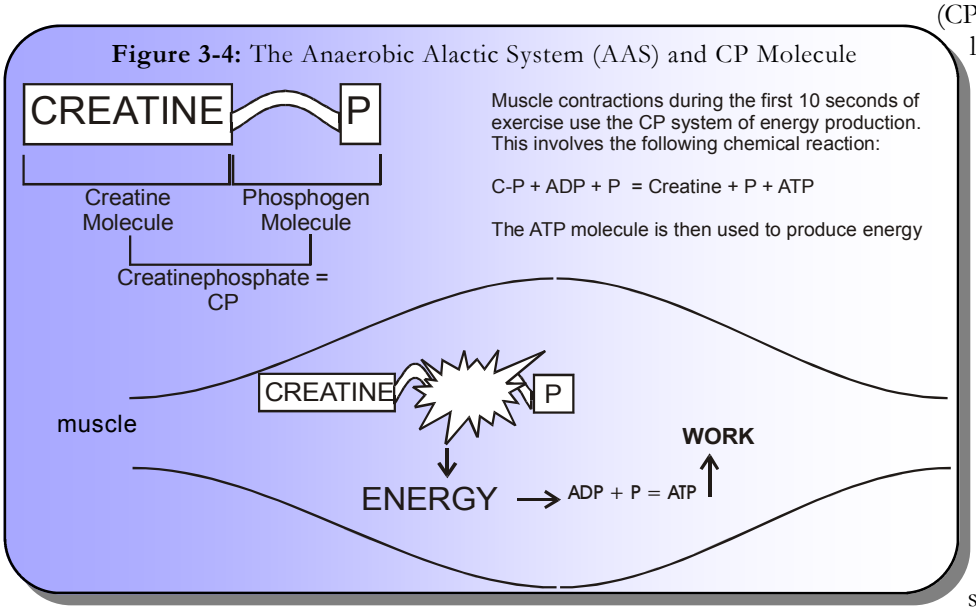


Three (3) Sources of ATP Production

1. Anaerobic Alactic System (AAS)

ATP is not the only high energy molecule found in muscles - the other is Creatine Phosphate (CP). ATP and CP molecules are located in the muscle cell's cytoplasm and are direct energy sources. Energy is produced in the absence of oxygen and does ***not*** produce lactic acid as a byproduct.

Figure 3-4: The Anaerobic Alactic System (AAS) and CP Molecule



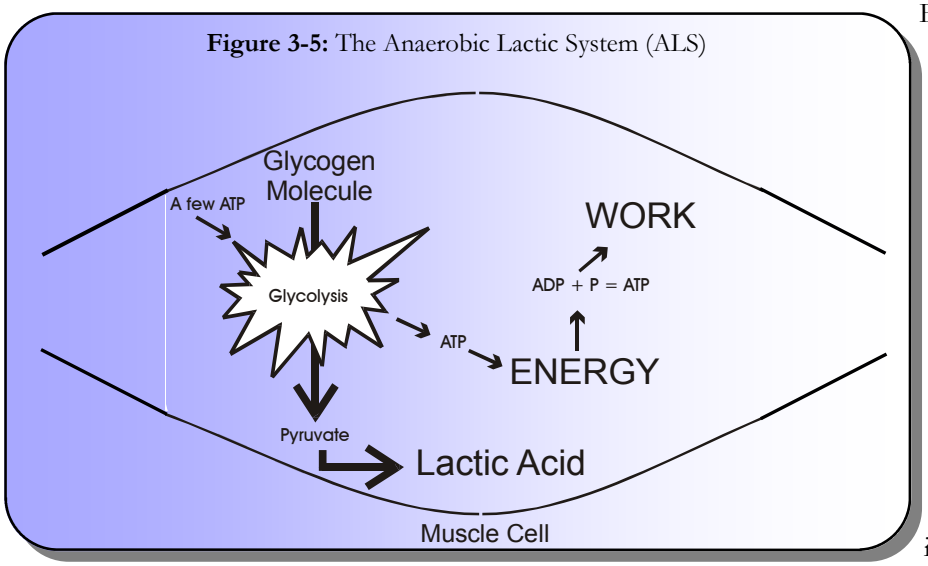
The primary function of CP is to resynthesize ATP. Figure 3-4 illustrates the resynthesis of ATP using the CP molecule.

The muscular stores of ATP and CP are limited and the amount of potential energy available is low. Energy production by this system lasts about 10 seconds (e.g. 100 metre sprint, shot put, golf swing, low repetition strength training).

2. Anaerobic Lactic System (ALS)

Anaerobic lactic metabolism is the partial breakdown of glucose in the absence of oxygen. Resynthesis of the ATP molecule occurs in the cytoplasm and is referred to as *anaerobic glycolysis*. Energy production using carbohydrates (primarily in the form of muscle glycogen) produces lactic acid (Figure 3-5). In the body, all carbohydrates are converted to the simple sugar glucose that can be used immediately as a fuel source or stored in the muscle for later use. The breakdown of carbohydrates in the anaerobic lactic system does not require oxygen.

Figure 3-5: The Anaerobic Lactic System (ALS)



Muscular fatigue is related to the anaerobic glycolysis byproduct, lactic acid that decreases a muscle fibre's pH level (more acidic). This pH change in the muscle interferes with energy production and eventually could inhibit muscular contraction.

The fate of lactic acid includes conversion to glucose ***or*** the conversion to carbon dioxide and water by the aerobic system.

The anaerobic lactic system is important because it provides a relatively rapid supply of ATP and is important in activities performed at a maximum rate for between 1 and 3 minutes such as the 400 and 800-metre sprints. The anaerobic lactic system is the primary system used during resistance training.

3. Aerobic System (AS)

Energy production via the aerobic system refers to the resynthesis of ATP using carbohydrate, fat, or protein sources in the *presence of oxygen* (Figure 3-6). The breakdown of carbohydrates, fats, muscle glycogen, and proteins involves a series of complex chemical reactions. Although fats and proteins are utilized as fuel for the aerobic system, the following 3 stages of aerobic metabolism apply primarily to carbohydrate molecules.

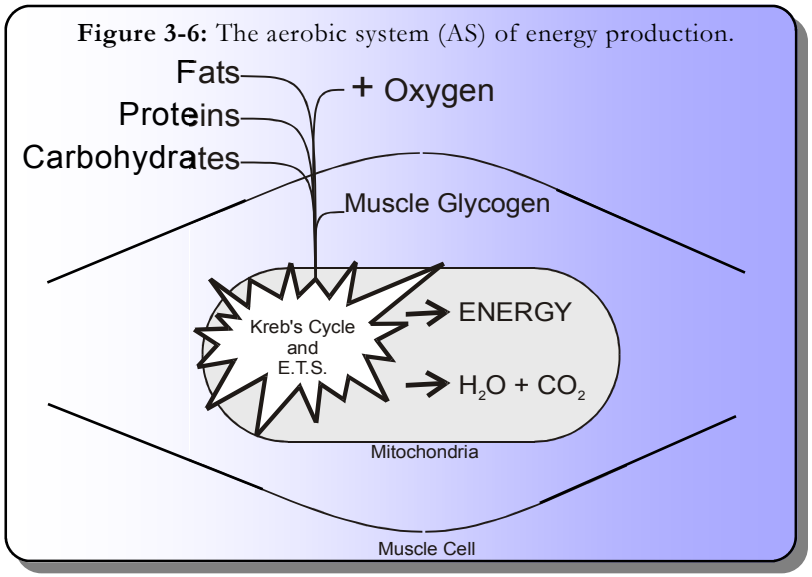


Figure 3-6: The aerobic system (AS) of energy production.

The 3 stages of aerobic metabolism of a carbohydrate molecule are:

1. The first series of chemical reactions are those of **Aerobic Glycolysis**. Aerobic glycolysis occurs when there is a sufficient supply of oxygen. Lactic acid does not accumulate because of the presence and availability of oxygen.
2. The **Kreb's Cycle** produces carbon dioxide (CO_2) and ATP. The Kreb's Cycle chemical reactions occur within the mitochondria in a muscle cell.
3. The **Electron Transport System** (ETS) produces water and ATP and occurs within the mitochondria in a muscle cell.

Unlike the byproducts of anaerobic lactic metabolism, the byproducts of aerobic metabolism are water and carbon dioxide. The carbon dioxide diffuses into the bloodstream, travels to the lungs and is expired. Some of the water is retained in the cell to regulate the homeostatic process.

In response to an increased carbon dioxide concentration in the blood, there is an increase in a positively charged ion (H^+). The increase in H^+ ions causes the blood pH to decrease (become more acidic) which results in muscular fatigue.

The system is characterized by low power generating capabilities because the use of oxygen in the chemical process is slower than those of the anaerobic process. The capacity of this system is very high because, if the intensity of an activity is low enough, there is an infinite amount of oxygen available to make energy (although other factors may impact this). The rate at which the ATP molecules are produced through the aerobic system is very slow when compared to the other 2 systems (Figure 3-7). The aerobic system requires more time to reach its maximal power output because of the need to adjust circulatory and respiratory systems to the demand of the activity. Endurance events which last from several minutes to several hours primarily utilize the aerobic system of energy production.

The fate of a fat molecule through aerobic metabolism is beta oxidation (the process of breaking down fat from long carbon chains into two carbon units) to the Kreb's Cycle to the ETS. The fate of a protein molecule through aerobic metabolism is protein degradation (protein is converted into amino acids) to the Kreb's Cycle to the ETS.

In summary, the Aerobic System metabolism of ATP involves substantial combustion of fuel in the muscle in the presence of oxygen. The fuel can be from sources within the muscle (free fatty acids and glycogen) and outside the muscle (free fatty acids from adipose tissue and glucose from the liver). As well, oxygen must be supplied to mitochondria in appropriate amounts for aerobic metabolism to contribute significantly to energy production.

CHAPTER SEVEN

Training Safety & Injury Prevention

Chapter Summary

Topics covered in this chapter are:

- Common Training Injuries
- Safety Considerations
- Injury Prevention Techniques
- Weight Room Safety
- Spotting Safety
- Weight Room Guidelines and Etiquette
- PAR Q
- Exercise Rating System
- Ergogenic Training Aids

After reading this chapter, you should be able to:

Learning Objectives

- Describe common strength training injuries.
- Understand safety considerations for the 'Famous 4' areas.
- Discuss injury prevention techniques.
- Discuss weight room safety considerations.
- Understand weight room guidelines and etiquette.
- Utilize the PAR Q form as designed.
- Understand how the exercises in the book are rated.
- Describe the use of weight lifting belts, knee wraps, wrist straps and hooks, and chalk.

Common Training Injuries

No one is immune from injuries while training. Even when perfect form is adhered to, it may be impossible to predict the actions of those training around you or the integrity of the equipment itself. However, most injuries occur because a person fails to control the weight and lets the weight control them. Think about the last time you were in the gym. How many people did you think were trying to perform an exercise, but were using far too much weight?

Several injuries may occur if correct form is not adhered to. **Strains** are injuries to muscles or tendons. Strains can be as minor as over-stretching a few muscle fibres or as serious as a complete tear. **Sprains** are injuries where excessive twisting or stretching of a joint occurs and a ligament tears or separates from the bone. Strains and sprains occur when a joint is forced to stretch through an extreme range of motion.

When a joint is displaced beyond its physiological range of motion this is known as a **dislocation**. Dislocations may also affect surrounding tissues. Common sites of dislocations are shoulders, thumbs, and fingers. The inflammation of a bursa is known as **bursitis**. Bursae are small sacs lined with synovial membranes filled with synovial fluid. Bursae function as a cushion between bone and skin or bone and tendons (i.e. between the elbow and the skin). **Tendonitis** is the inflammation of the tendon sheath. Tendon sheaths are similar to bursae. Tendon sheaths are synovial sacs that wrap around tendons to decrease friction where tendons cross joints. To decrease the chances of developing tendonitis avoid overusing a particular joint. A **herniated disc** is where the intervertebral disc is damaged due to improper loading of the spinal column. The herniated disc may place pressure on spinal nerves causing pain, sensory and / or motor changes.

Safety Considerations

Some people are genetically prone or predisposed to injuries through the process of resistance training. For example, predisposition may manifest itself via personality trait (Type A) or joint structure (elbows which hyperextend). The four areas commonly prone to injury, known as the "Famous 4" are the shoulders, neck, lower back and knees. Other areas susceptible to injury are the elbows and wrists. Below is a list of exercises which may aggravate specific areas.

Shoulders

- Exercises for the rotator cuff muscles using heavy loads.
- Failing to exercise the deltoids for balance (anterior, medial, and posterior heads).
- Over-exercising the anterior deltoid.
- Improper lat pulldown technique (i.e. behind the neck).
- Heavy dumbbell shoulder presses.
- Locking out the elbows during barbell bench presses (flat, incline, or decline).
- Behind the neck pull-ups (chins).
- Dumbbell pullovers.
- Barbell bench presses where horizontal shoulder abduction exceeds 90 degrees.
- Improperly adjusted pectoral flye machines.
- Upright rows, especially with internal rotation.
- Straight arms while performing dumbbell lateral, anterior or posterior raises.
- Certain stretches for the muscles of the shoulder and chest.
- Wide grip or deep triceps dips.

Neck

- Raising the head off the bench while performing exercises such as barbell or dumbbell chest press.

- Any neck strengthening exercises.
- Hyper-extending the neck to watch form in a mirror.
- Incorrectly placing barbell on spinous process during squat.

Lower Back

- Remember, most exercises can affect the lower back if performed incorrectly.
- High risk exercises such as the squat, cleans, or modified deadlifts that require significant training experience and practice.
- Contraindicated exercises such as deadlifts or goodmornings.
- Rotation of the spine against a resistance (i.e. torso twist machine).
- Lifting the hips off the bench during heavy, prone hamstrings curls.
- Back hyperextension during standing barbell or dumbbell biceps curls.
- Picking up weights (plates, dumbbells) with improper lifting techniques or body mechanics.
- Using a 'hip flexion and extension' motion to build momentum during heavy seated row or lat pulldown exercises.

Knees

- Low cable adductor or abductor pulls.
- Incorrectly adjusted adductor / abductor machine.
- Improperly adjusted 4-way hip machine.
- Improperly adjusted leg extension machine.
- Squats or incline leg press with toes pointed inward.
- Failing to align the hips, knees, and ankles during the squat, leg press, leg extension, etc.
- Heavy load on leg extension machine.
- Locking out the knees in full extension.
- Hyper-extending knees.
- Uncontrolled descent while performing squat.
- Deep squats (knee angle less than 90 degrees).

Elbows

- Locking out the elbow in the extended position during any exercise or stretch.
- Deep triceps dips.
- Certain preacher curl benches.
- Narrow grip on the bar during barbell bench press.

Wrists

- Improper bar positioning (i.e. load of the barbell or dumbbell not directly over the forearm).
- Failing to immobilize wrist(s) while performing certain exercises (e.g. triceps pressdowns).
- Narrow or wide grip bench press.
- Narrow or wide grip barbell curls.
- Heavy wrist curls and wrist extensions.

Everyone would like to avoid training injuries, but they do occur. So, what should be done if an injury occurs? First and foremost, seek a professional evaluation - never underestimate the severity of an injury. If a professional evaluation is not immediately available, the following information may be suggested to a client. Note***: this information should never be used as a substitute for medical help***.

CHAPTER EIGHT

Leg Exercises

Muscle Summary

Quadriceps
Vastus medialis, Vastus lateralis, Rectus femoris, Vastus intermedius

Hamstrings
Semimembranosus, Semitendinosus, Biceps femoris

Adductors
Adductor magnus, Adductor longus, Adductor brevis, Pectineus, Gracilis

Abductors
Gluteus medius, Gluteus minimus, Tensor fasciae latae

Calves
Gastrocnemius, Soleus

Exercises

Basic Barbell Squat
Hamstrings Curl (Leg Curl)
Universal Leg Press
Lunges
Calf Raises (Standing)
Hip Flexion
Hip Abduction

Smith Machine Squats
Front Squats
Hack Squats
Calf Raises on Leg Press Machine
Standing Single Leg Calf Raises

Modified Deadlift
Leg Extension
Incline Leg Press
Universal Machine Squat
Seated Calf Raise Machine
Hip Extension
Hip Adduction

Other Exercises:
Standing Leg Curls
Straight-Leg Deadlifts
Step-Ups
Donkey Calf Raises

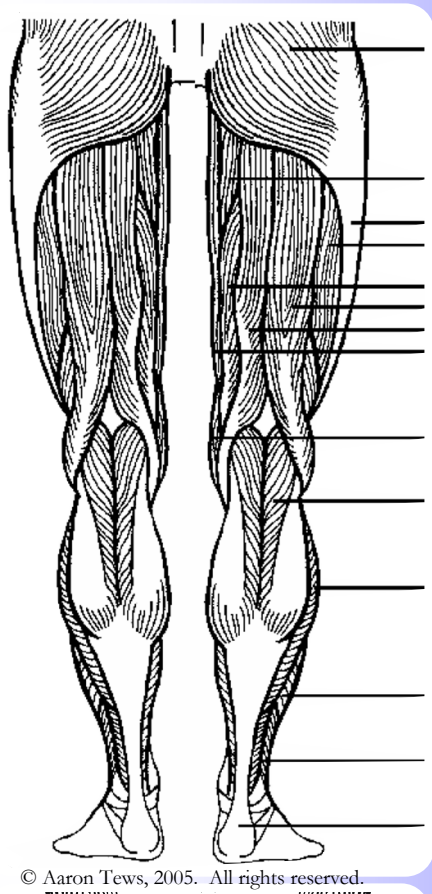
Muscles of the Lower Body (Legs)

Chances are, when lifting weights, a significant portion of training will be dedicated to lower body development. Strong, well-developed legs help people run faster, jump higher, throw farther, they also form a solid foundation for the rest of your body.

Many people overlook the importance of stability and balance in their training because they have been programmed to focus on muscular strength and definition instead. Building a supportive base is an important prerequisite for the safest, most effective development of strength. This often holds true for lower body development. Exercises such as the lunge are not usually performed, yet this exercise can develop the stability of the hip and knee joints effectively. Also, the balance of strength between the quadriceps group and hamstrings group is often not considered. It is recognized that the hamstrings should be about 80%+ the strength of the quads. So, as an instructor, insure balance and stability are considered and incorporated when designing training programs.

Diagram 8-1 is a superficial view of both the posterior thigh / leg muscles and the anterior thigh muscles. Although a strength training instructor is not *required* to know all the muscles in the diagram, it is suggested that an instructor learn them.

Diagram 8-1: Superficial view of the posterior thigh / leg muscles and anterior thigh.



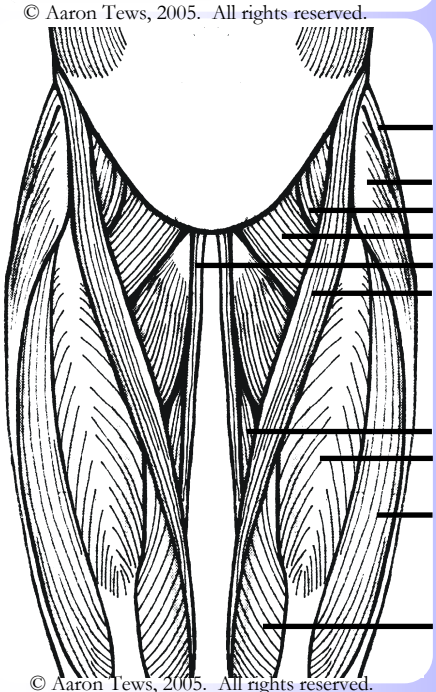


Diagram 8-2: Cross sectional view of the thigh/leg muscle compartments

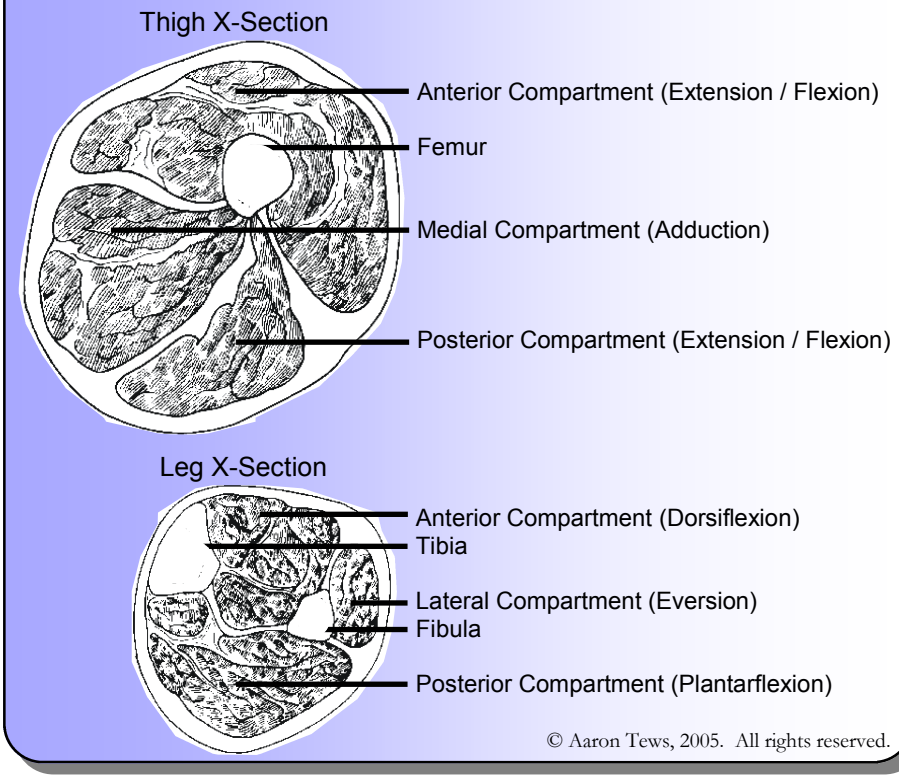


Diagram 8-2 illustrates the compartments of the thigh and leg. It is important to understand compartments because it helps one understand muscles as functional groups and injuries and syndromes (e.g. Anterior compartment syndrome).

Table 8-1 outlines the muscles and muscle groups associated with each compartment. Muscles listed in brackets are not shown on the diagrams.

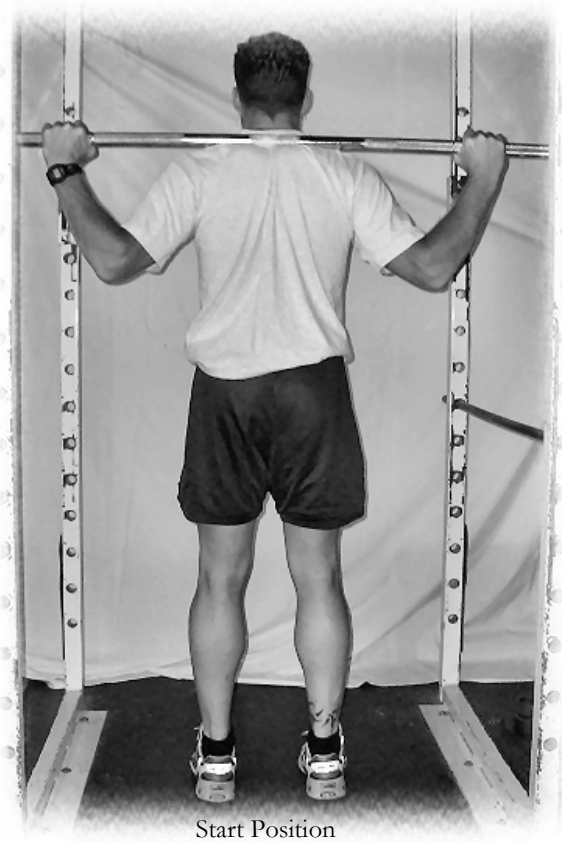
Table 8-1: Muscles of the thigh and leg (below).

Compartment	Composed of	Muscle Function
Medial	Adductor magnus	\
	Adductor longus	>Adducts thigh
	Adductor brevis	/
	Gracilis	Adducts thigh, flexes leg
	Pectineus	Adducts, flexes, rotates thigh
Anterior	Sartorius	Flexes thigh and leg, laterally rotates thigh
	Rectus femoris	Extends leg, flexes thigh
	Vastus medialis	\
	(Vastus intermedius)	>Extends leg
	Vastus lateralis	/
Posterior	Semimembranosus	\
	Semitendinosus	>Flexes leg, extends thigh
	Biceps femoris	/
Other	Gluteus maximus	Extends, laterally rotates thigh
	Gluteus medius	Abducts, medially rotates thigh
	(Gluteus minimus)	Abducts, medially rotates thigh
	Tensor fasciae latae	Assists - flex, abduct, medial rotation thigh
	Iliacus	Flexes the thigh
	Psoas major	Flexes the thigh, medial rotation
Anterior	Tibialis anterior	Dorsi-flexes, inverts foot
	(Extensor hallucis longus)	Dorsi-flexes, inverts foot
Lateral	Peroneus brevis	Plantar flexes, everts foot
	Peroneus longus	Plantar flexes, everts foot
Posterior	Gastrocnemius	Flexes leg, plantar flexes foot
	Soleus	Plantar flexes foot
	(Plantaris)	Flexes leg, plantar flexes foot

Basic Barbell Squat **Advanced**

Description: For many, the squat is considered 'the' exercise for leg development. This exercise is considered highly advanced because of the degree of lifting experience required to perform correctly. This exercise should be attempted by experienced lifters and explained by qualified instructors. Many injuries in the weight room are squat related - very few people perform the squat correctly.

Start Position



Start Position

Finish Position

Muscle Actions Involved

Descending phase (squat position):	Ascending phase (standing position)
Flexion at hip joint	Extension at hip joint
Flexion at knee joint	Extension at knee joint
Dorsi-flexion at ankle joint	Plantar flexion at ankle joint

Muscles Involved

Primary Involvement	Moderate Involvement	Stabilizers
Vastus lateralis	Rectus femoris	Erector spinae (isometric)
Vastus intermedius	Adductor magnus	Hamstrings Group
Vastus medialis	Adductor brevis	
Soleus	Adductor longus	
Gluteus maximus	Gluteal group	

* The squat, using a narrower than shoulder width stance, involves the above mentioned muscles of the legs according to MRI studies. The hamstrings muscle group, commonly believed to be involved during the squat is not involved according to MRI studies.

Movement Execution

> Adjust the barbell in the squat rack to approximately mid to upper chest height.
> Rest the barbell behind your neck (comfortably across the upper traps and shoulders).
> The grip on the barbell will vary from person to person, but is usually slightly wider than the shoulders.
> Stance - your feet should be hip width apart with the toes pointed straight forward or slightly outward.
> Your body weight should be equally distributed over both feet.
> Inhale and descend into the squat position - where a 90° angle is formed at your knees (see diagram).
> While descending, concentrate on:
  1. Lowering your hips and buttocks behind your heels.
  2. Keeping your back in its normal, slightly arched position.
  3. Looking straight ahead - into the mirror is the best.
  4. Keeping the barbell directly above your heels (see diagram) but never farther forward than your toes.
  5. The buttocks - should not protrude excessively backwards, but lowered straight down.
  6. Your knee position - should not travel farther forward than the toes during the descent.
  7. Speed of descent - never descend too fast - a 3 second descent is good.
  8. Your heels - must remain in contact with the floor throughout the range of motion.
> Avoid pausing in the finish position - stopping the barbell at the bottom of the range of motion may require excessive forward lean to raise the barbell.
> While exhaling, return to the starting position.
> Maintain the normal lower back arch while ascending.
> No matter how heavy the weight, do not lock out the knees at full extension.

Instructor Safety Tips

1. How deep is too deep when performing the squat? To work a full range of motion, the glutes would touch the heels, but this places undue stress on the knees. So, for the general public exerciser or the recreational bodyshaper, knees to 90° is deep enough (when performed correctly). Only experienced or professionally supervised weight lifters should perform full squats.
2. If your heels continually lift off the floor while performing the squat, work on your Achilles' tendon and hamstrings flexibility. If you cannot perform this test successfully, you may want to avoid performing the squat until you improve your flexibility. To test Achilles' tendon flexibility:
   1. Stand up straight (without any weight)
   2. Place feet together
   3. Squat until your glutes touch your heels
   4. You should be able to do this without falling over backwards or your heels raising off the floor.
3. Never place a board under your heels to compensate for poor Achilles' tendon flexibility. This only aggravates the problem and increases susceptibility to low back and knee injuries.
4. This exercise requires good lower back and abdominal strength to keep the spine supported properly to prevent the back from buckling.
5. Use a spotter correctly. A spotter should watch for incorrect technique including:
   A. Hip shift during execution to favor a stronger leg. This generally occurs during the last portion of the descending phase and beginning of the ascending phase. It occurs when a person has a stronger leg and the body tries to compensate for the imbalance. If hip shift is not corrected early, it can become a major problem to correct in the future.