Trainining for Hypertrophy

Allen Hedrick, MA, CSCS
Assistant Strength and Conditioning Coach
U.S. Air Force Academy

THE PRIMARY GOAL IN BODYBUILDING is to achieve a high level of muscle hypertrophy, and resistance training is the method used to achieve this goal. By contrast, in other sports resistance training is used to improve performance or reduce the chances of injury. However, for sports in which increases in body weight or strength are advantageous to performance, training for hypertrophy may also be appropriate.

This article will give the strength and conditioning coach a general review of the physiological aspects involved with muscle hypertrophy. More important, it will explain how these principles can be applied to training when muscle development is the goal.

In sports such as football (see Figure 1), and for specific positions such as center in basketball, increases in lean body mass can enhance performance. Of course performance in most physical activities is also enhanced when there is an increase in strength in the appropriate muscle groups (21). Because there is a positive relationship between the strength of a muscle and its cross-sectional area (18, 24), an increase in muscle size can be beneficial when the goal is an optimal increase in strength.

The Hypertrophy/Hyperplasia Controversy

One point of controversy in the area of strength physiology is whether resistance training induces the muscle to increase in size through hypertrophy only, or whether hyperplasia also plays a role (5, 8, 16).

There are two schools of thought concerning how muscle enlargement takes place. The first holds that hypertrophy alone is responsible. Hypertrophy occurs as a result of an increased cross-sectional area of the existing muscle fibers. In other words, the existing fibers increase in size.

The second school of thought holds that increases in muscle cross-sectional area also involve hyperplasia. Hyperplasia is a process in which muscle fibers split, leading to an increase in the total number of muscle fibers. It may also occur as a result of additional muscle fibers developing from satellite cells (12).

As will be reviewed here, some studies have supported and others have discounted the occurrence of hyperplasia in humans.

Support for Hyperplasia

Some researchers have reported fiber splitting as well as hypertrophy in response to resistance training. Much of the support for hyperplasia comes from studies involving bodybuilders. Some studies have found that despite the tremendous muscle mass of elite bodybuilders, these athletes did not have relatively enlarged muscle fibers (17, 25).

Similarly, fiber size in the deltoideus and vastus lateralis muscles of elite bodybuilders were found not to be any larger than those of nonathletes, and were smaller than those of weightlifters and powerlifters (23). It was theorized that muscle enlargement was due to an increased total number of muscle fibers rather than to an increase in the size of individual muscle fibers.

The hypothesis of exercise-induced hyperplasia is also sup-
ported by studies of athletes relying on both muscular power and endurance, such as swimmers and kayakers (23). These athletes have displayed hypertrophied deltoids despite surprisingly small fiber diameters. Tesch (23) suggested that long-term systematic and intense strength training may result in hyperplasia, but noted that this does not dispute increases in muscle size occurring primarily as a result of an increase in the size of individual muscle fibers.

Additional support for hyperplasia comes from a study in which cats simulated weight training (11). In that study, Gonyea found that, as a result of resistance training, cats demonstrated an increase not only in muscle fiber diameter but also in fiber number.

Criticism of Hyperplasia Studies
As noted, investigations using animals indicated that hyperplasia occurs as a result of resistance training. However, it has been suggested that these studies were characterized by several methodological weaknesses.

Abernethy et al. (1) noted that most of these studies examined only single or multipennate muscles. Additionally, fibers were counted only at a single cross-sectional level. Thus changes in pennation may have accounted for the increased fiber number reported. This criticism could have been negated had all the fibers within a muscle been counted (1). Another criticism of hyperplasia studies is that damage to the muscle sample as well as degenerating muscle fibers may have accounted for the observed hyperplasia (7).

In defense of those studies supporting hyperplasia, it must be noted that some of these methodological weaknesses were eliminated in later studies by using nitric acid digestion to digest con-
nective tissue so that all fibers could easily be counted under a dissecting microscope (12).

It has also been suggested that the lack of hypertrophied muscle fibers in bodybuilders does not mean that increases in muscle mass were due to hyperplasia. Postmortem investigations have found significant interindividual differences in fiber number between human cadavers (1). In addition, there is a surprisingly great variation in total fiber number in muscles obtained from infants; this points to the different muscle growth potential in humans (2).

Therefore the additional muscle fibers found in bodybuilders may well be due to genetic endowment rather than to training-induced hyperplasia (16). This suggests that genetic endowment may lead to a natural selection. That is, athletes who are predisposed to success in activities requiring superior strength or muscle development tend to choose those activities. This is in agreement with the general belief that fiber number is established at birth, or shortly after, and that no net increase in fiber number occurs as a result of training (2, 16).

Hypertrophy

It has long been recognized that hypertrophy is the major mechanism involved in enlarging muscle in response to resistance training. Muscle enlargement is produced by repeated bouts of high intensity muscle contractions, as in resistance training. Thus muscle hypertrophy is an important adaptation to resistance training.

For example, Abernethy et al. (1) found the cross-sectional area of the medial and lateral knee extensors of bodybuilders to be 29 and 49% greater, respectively, than those of physical education students. Laboratory animals have also demonstrated muscle hypertrophy as a result of resistance training (7).

Hypertrophy Process

Heavy resistance training leads to an increase in the cross-sectional area, or size, of skeletal muscle fibers. This is a direct result of increased contractile protein (i.e., actin and myosin), as evidenced by an increase in both myofibril area and numbers (16).

Exposure to resistance training stimulates protein synthesis (10). Indeed, a single bout of heavy-resistance training can increase muscle protein synthesis for up to 24 hrs postexercise (22). Such increases in protein synthesis undoubtedly contribute to an increase in the amount of contractile proteins, ultimately leading to a significant increase in cross-sectional area (6, 25).

Electron microscope investigations of training-induced hypertrophy in human muscle reveal that the increases that occur in fiber area are directly related to an increase in both the myofibril area and myofibril number. The new myofilaments are added to the external layers of the myofibril, resulting in an increase in its diameter (6). These adaptations create the cumulative effect of enlarging the fiber and the associated muscle group. This hypertrophy may be observed within 2 months of training (23).

Hypertrophy and Fiber Type

Although strength training results in an increase in cross-sectional area of all fiber types, most studies indicate that a greater relative hypertrophy occurs in the type II, or fast-twitch, fiber units than in type I, or slow-twitch, fiber units (7, 16, 23). Additionally, fiber hypertrophy appears to follow the sequence of type II fiber preceding type I fiber hypertrophy (1).

Since both fiber types are probably recruited equally in the performance of maximum or near maximum contractions, the greater hypertrophy of the type II fibers may reflect a greater relative involvement of these high threshold units than would normally occur during daily activity.

Program design can affect the amount of hypertrophy seen in the two major fiber types. Training for strength requires high resistance, near maximal muscular contractions over a small number of repetitions, coupled with full recovery between sets. This type of training protocol leads to increases in the cross-sectional area of the exercised muscles, with type II fibers increasing more readily and at a faster rate than type I fibers (27).

This is significant for strength and power athletes because type II fibers contract with greater velocity than do type I fibers. There is also an indication that the strength per unit of type II fibers may be twice that of type I fibers (19). Selective hypertrophy of type II fibers, which has been shown to occur with resistance training, could therefore be one reason for the observed increases in specific tension.

In contrast to this, bodybuilders, who train at a higher volume and lower intensity than strength athletes, do not demonstrate se-
lective hypertrophy of type II fibers. Thus athletes who train at lower intensities and high volume show a greater degree of hypertrophy in type I fibers (6).

**Hypertrophy in Women**

Numerous studies have evaluated adaptations of muscle to resistance training in men, but little is known about muscle adaptations in women. Unit for unit, muscle tissue in both sexes is similar in force output. And there is evidence of similar proportional increases in strength performance and hypertrophy of muscle fiber relative to pretraining status for both sexes (14).

Men demonstrate greater increases in absolute hypertrophy as a result of resistance training. However, relative increases in men and women can be viewed as changes that are proportional to the pretraining size of the muscle fibers, and men typically have greater muscle fiber size than women. Thus women and men do respond to strength training in very similar ways (14).

For example, Staron et al. (22) found that similar to strength-trained men, resistance training resulted in considerable hypertrophy in women. Although increases in the cross-sectional area of the muscle fibers were not detectable from thigh girth measurements, anterior thigh skinfold measurements decreased significantly. This suggests a decrease in subcutaneous fat and an increase in whole-muscle cross-sectional area. It was concluded that, like men, women are capable of responding to heavy resistance training with significant increases in the cross-sectional area of their muscle (22).

Empirical observations of bodybuilders suggest that women may be capable of substantial increases in muscle mass (2). The possibility of women making such dramatic gains in muscle fiber size is not entirely surprising, given these empirical observations and prior investigations that have demonstrated such increases (22).

In contrast to this, other studies have found very little hypertrophic response in women as a result of resistance training. Fleck and Kraemer (7) cited a study in which the largest increase in limb circumference after 10 weeks of resistance training was only 0.6 cm. Simple observation would also suggest that most women do not achieve the same degree of hypertrophy as men do in response to resistance training.

That some women do demonstrate a greater hypertrophic response to resistance training than others may be explained by the following factors: (a) higher than normal testosterone levels, (b) lower than normal estrogen relative to testosterone levels, (c) a genetic disposition to develop greater muscle mass, or (d) a willingness to participate in more intense resistance training than the average woman is willing to tolerate (7).

Another explanation for the lack of hypertrophy in most women was suggested by Alway et al. (2), who evaluated the biceps muscles of male and female bodybuilders. They found that the large cross-sectional area of the male bodybuilders' biceps was due to adaptations in type II muscle fibers. Male bodybuilders had a greater proportion of type II than of type I fiber areas.

In contrast, female bodybuilders did not show preferential hypertrophy in type II fibers but instead had similar adaptations in both fiber types. This could limit muscle enlargement in women compared to men. Alway et al. (2) admitted that type II fibers may have responded to relative training loads that were different between subject groups.

**Additional Considerations**

Increases in fiber size due to resistance training are accompanied by proportional increases in interstitial connective tissue. While the absolute amount of connective tissue increases with strength training, this can only be considered as having a minor effect in total muscle size (16).

Research has revealed that bodybuilders exhibit a larger absolute amount of collagen and other noncontractile connective tissue than do untrained subjects; this also contributes to increases in overall muscle size (6). Although endurance training increases the capillary-to-fiber ratio, resistance training has little or no effect on this ratio. In studies wherein training led to significant increases in fiber area, this value actually decreased, possibly due to the dilution effect of increased contractile protein (16, 23).

A possible exception to this may occur in bodybuilders, who perform lower intensity and higher volume training than other strength athletes. Capillary densities similar to those of untrained subjects have been found in bodybuilders (16, 23). Similar to the capillary-to-fiber ratio, mitochondrial density also decreases as a result of muscle hypertrophy (24).

**Hormonal Factors**

Another factor that influences muscle hypertrophy is circulating hormones. Resistance training places a unique demand on the body because significant amounts of force are produced, requiring the activation of high threshold motor units. These high threshold motor units are not typically
stimulated by other types of exercise (15). The muscle fibers of the activated motor units are stimulated, and forces are placed on the sarcolemmas of the muscle fibers because of the demands on the body during resistance training.

Responses to the force production stress include alterations in sarcolemma permeability to nutrients as well as sensitivity and synthesis of receptors (i.e., hormonal binding sites) in the muscle cell membrane. One way the body responds to this stress is by releasing hormones. Three of the more important hormones involved with muscle hypertrophy are testosterone, human growth hormone (GH), and insulin-like growth factors (IGF).

**Testosterone**

The measurement of serum testosterone is a method of evaluating the anabolic status of the body. In addition to directly affecting muscle growth because of its role in protein synthesis, testosterone may indirectly affect the protein content of the muscle fiber by promoting GH release, which leads to IGF synthesis and its release from the liver (15).

Men have about 10 times the amount of androgens (primarily testosterone) as do children and women, although women do demonstrate wide interindividual differences. While testosterone is not solely responsible for exercise-induced muscle hypertrophy, the significantly higher levels of testosterone in males may help to explain the observed differences between the sexes and between children and men (7).

Before the age of 10 to 12 there is no significant difference in strength between boys and girls (3). After this age, however, boys continue to show increases in strength for several years while most girls do not show continued increases in strength. The most likely explanation for the continued development of strength in pubertal males is their greater secretion of testosterone.

According to Hakkinen et al. (13), some women demonstrate high levels of strength and/or musculaarity due to high interindividual differences in serum testosterone levels. It was found that women with low average testosterone : sex hormone binding globulin (SHBG) ratios did not increase muscle mass to the same degree as those with high serum testosterone : SHBG ratios.

Within the limitations of Hakkinen et al.'s study, it seems that the basic concentration of blood testosterone was of great importance for muscle hypertrophy and strength development during strength training. Because of this, blood testosterone levels in women may be an important indicator of individual trainability even during short-term strength training (13).

Furthermore, some (14), but not all (13, 22), studies have found that weight trained women have higher preexercise levels of total serum testosterone than untrained women, and that testosterone levels increase in women during a weight training session (14). This may account for some of the interindividual differences in testosterone levels found in women.

**Effect of training on testosterone.** Resistance training has been found to cause a significant short-term increase in resting serum tes-tosterone concentrations in men (15, 22). It appears that, in young males at least, several factors can be manipulated to influence acute serum concentrations, which may be important if significant increases in strength and hypertrophy are the goal of training (15):

1. Select exercises that involve a large amount of muscle mass (e.g., power clean, deadlift, squats).
2. Utilize a heavy resistance (85 to 95% of 1-RM).
3. Make use of a moderate to high volume of training by performing multiple sets and/or multiple exercises.
4. Emphasize short rest periods (30 sec to 1 min).

**Human Growth Hormone**

Another hormone with potentially significant anabolic effects is human growth hormone (GH). It is directly involved with the growth process of skeletal muscle, and many other tissues in the body. It also appears that GH plays an important role in helping the body adapt to the stress of resistance training. According to Kraemer (15), the physiological roles of GH include the following:

- increases amino acid transport across cell membranes;
- increases protein synthesis;
- increases availability of glucose and amino acids;
- increases collagen synthesis;
- stimulates cartilage growth.

**Effect of training on GH.** Similar to testosterone, concentrations of serum GH can be enhanced by manipulating certain exercise variables. It has been shown that in resistance training, GH is sensitive to both rest periods and intensity of exercise (7, 24).

When exercise intensities of 10-RM were used while performing 3 sets, combined with rest periods of 1 min, large increases in serum concentration of GH were observed in men (15). Using an identical exercise protocol with women also resulted in significant increases in serum GH. Thus, combining a moderate number of repetitions (i.e., 10 reps) with short rest...
### Table 1
**Example Hypertrophy Cycle**

*Note:* This is the hypertrophy cycle used for offensive linemen at the U.S. Air Force Academy.

**Cycle:** Hypertrophy  
**Goal:** Increase muscle hypertrophy  
**Length:** 6 weeks  
**Intensity:** Complete full no. of required reps on each set prior to increasing resistance.  
**Pace:** The Olympic-style lifts are performed explosively. All other exercises, lift in 3 sec, lower in 5 sec.  
**Rest:** Rest periods are 2 min between total body lifts, 1 min between all other exercises.

**Sets/Reps:**
- **Weeks 1-2:** Total body, 4 x 6; Core lift, 4 x 10; Auxil. lift, 3 x 10
- **Weeks 3-4:** Total body, 4 x 4; Core lift, 4 x 12; Auxil. lift, 3 x 12
- **Weeks 5-6:** Total body, 4 x 5; Core lift, 4 x 8; Auxil. lift, 3 x 8

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**Variable manipulated to increase hypertrophic effect**

*Intensity:* Intensity is set so athlete selects the heaviest resistance possible that still allows completion of full no. of required reps on each set prior to increasing resistance for the next workout. This ensures high training vol.

*Rest:* Rest periods restricted to 2 min between total body lifts and 1 min between all other exercises to take advantage of the positive effect of high vol/short rest periods on serum testosterone and GH levels.

*Sets/Reps:* Multiple sets (3 to 4) of each exercise are performed. Repetitions (excluding Olympic-style lifts) range from 8 to 12 to maintain high training vol.

**Additional considerations**

When training for hypertrophy, 2 to 3 exercises per body part are recommended; however, time restrictions make that impractical for college athletes. Instead the emphasis was on training the major muscle groups of the body with complex lifts (e.g., front squat/press) and multisegmented lifts (e.g., squats).

*Pace of training:* The pace of training has not been shown to affect hypertrophy, yet it seems that increasing the duration of training by slowing the movement would enhance the hypertrophic effect. Thus the pace of training (excluding Olympic-style lifts) is set at 3 sec up and 5 sec down.

**Terminology**

*Total body exercise:* one of the Olympic-style lifts; *Core lift:* a multijoint exercise (e.g., squat); *Auxiliary lift:* a single joint exercise (e.g., biceps curl); *DB:* dumbbell exercise; *SDLs:* still-leg deadlift; *RDL:* Romanian deadlift; *MR:* manual resistance exercise; *WT:* weighted exercise.
periods (i.e., 1 min) is effective at elevating serum concentrations of GH in both men and women.

**Insulin-like Growth Factors**

The most important aspect of insulin-like growth factors (IGF), in terms of increases in muscle mass and strength, is that IGF directs many of the effects of GH (15). Exercise stress, acute hormonal responses, and the demand for muscle, nerve, and bone tissue remodeling at the cellular level each influence many of the mechanisms involved with IGF.

With male subjects, almost all exercise protocols will result in increases in IGF concentrations at some point over a 2-hr period following training. Contrasted with that, a study using the same type of exercise protocol in women found no changes in IGF concentration (15).

The specific responses of IGF to heavy resistance training have yet to be fully understood. As with GH, training-induced adaptations in IGF are probably reflected in a variety of release, transport, and receptor interaction changes.

### Exercise Protocol for Hypertrophy

Although a variety of resistance training protocols will result in hypertrophy, especially in untrained individuals, it is possible to manipulate specific training variables to optimize the hypertrophic response. Generally, when training for hypertrophy the following guidelines are recommended (24):

- Use lighter training loads so that you can complete a greater volume of training, typically a 10- to 12-RM load on each set.
- Use a high volume of training, accomplished with multiple sets (3 to 4) and multiple exercises (4 to 5) per body part.
- Keep rest periods short to moderate in duration (60 to 90 sec) because it is important to begin the next set of exercises before achieving full recovery.

This is in agreement with many of the principles that guide bodybuilders, whose ultimate goal, after all, is superior musculature. These athletes naturally adhere to principles that have been proven effective at achieving increases in muscle size. A quick perusal of articles describing bodybuilding programs (4, 9, 20, 26) shows that these programs call for high repetitions (8 to 20) and multiple sets (3 to 4). Table 1 shows how these guidelines can be put into practice.

### Additional Considerations

It has been suggested that the hypertrophic response depends not only on the intensity of the exercise but also on the length of time the muscle is under tension. However, a study evaluating the effects of speed of movement during resistance training did not find this to be true (28). It was expected that the group that trained with slow controlled movements might achieve greater gains in hypertrophy than the group training with high-speed contractions, but this was not supported by the findings. Since hypertrophy development was similar for both groups, it appears that speed of contraction may not be a factor.

### Summary

Muscle development in response to resistance training is still the subject of controversy. Most recent evidence seems to suggest that increases in the cross-sectional area of the muscle are due to hypertrophy only. Hypertrophy is a direct result of increases in the contractile proteins, as evidenced by an increase in both myofibril area and numbers. It occurs generally in type II fibers; however, program design has a major influence on the degree of hypertrophy seen in the two fiber types.

Men show a greater hypertrophic response than women, most likely because of higher testosterone levels and because men may show more preferential hypertrophy in type II fibers than women.

Hormonal factors play a significant role in hypertrophy. Three of the more important hormones involved are testosterone, GH, and IGF. Testosterone is important because of its role in protein synthesis. Men have about 10 times the level of testosterone as do children and women.

GH is directly involved with the growth process of skeletal muscle. It also plays a major role in helping the body adapt to the stress of resistance training. The importance of IGF is that it mediates many of the effects of GH. Both testosterone and GH levels are positively affected by exercise protocols calling for moderate to high repetitions and short rest periods.

When the goal of training is hypertrophy, the typical program employs the following variables:

- Repetitions are in the range of 6 to 12.
- Multiple sets (3 to 4) and multiple exercises per body part (4 to 5) are performed.
- Rest periods are short so that the muscle is worked prior to full recovery; this also enables the individual to take advantage of the elevated levels of testosterone and GH that occur with short rest periods.
References


Allen Hedrick has worked as assistant strength and conditioning coach at the U.S. Air Force Academy in Colorado Springs since November 1994. Prior to that he was employed as strength/conditioning coordinator at the U.S. Olympic Training Center in Colorado Springs. He earned a master's in exercise science from Fresno State University.