Hormones, secreted by endocrine glands in the body, are substances that regulate the function of body cells, tissues, organs or systems. Hormones are released from a number of "traditional" glands, such as the pituitary, testes, ovaries, pancreas and thyroid and the adrenal cortex. More recently, science has also documented hormone secretion from "nontraditional" sites, such as the heart, kidney, liver and adipose tissue. In reference to gender, the major distinctions between male and female endocrinology (the study of hormone-secreting glands) come down to differences in the reproductive structures (testes versus ovaries). Males produce high levels of testosterone and much lower levels of estrogen and progesterone; females produce high levels of estrogen and progesterone and much lower levels of testosterone.

Exercise places a major challenge on the body owing to the increased energy it requires and the physiological demands it puts on the body's nervous, muscular, cardiovascular, metabolic and respiratory systems. As a body responds and subsequently adapts to exercise, a number of complex hormonal interactions occur simultaneously. For example, hormones can increase blood pressure, stimulate protein synthesis and increase the body's metabolic rate. Several hormonal responses and consequent adaptations to resistance training are discussed in this article.

**Energy Production**
With resistance exercise, there are immediate increases in epinephrine and norepinephrine (Kraemer & Ratamess 2005). These two hormones raise blood glucose and are important for increasing force production, muscle contraction rate and energy production (i.e., the synthesis of ATP-the energy currency of cells). Levels of these hormones actually begin to rise prior to the resistance training workout (Kraemer & Ratamess 2005); this is an anticipatory response of the body preparing for the challenging exercise to follow. Interestingly, the elevated blood glucose levels do not typically lead to an increase in insulin unless protein/carbohydrate supplementation precedes the workout (Kraemer & Ratamess 2005). The greater uptake of blood glucose by the skeletal muscle occurs because of an increase in function by the cell's glucose transporters, which raises metabolism in the muscle cell. Regular resistance exercise training has been shown to increase insulin sensitivity, meaning the body can take in and use glucose more effectively (Pollock et al. 2000).

**Training Volume**
In resistance exercise, total volume is easily calculated by multiplying number of repetitions (reps) x number of sets x weight in either a single session of resistance exercise or a long-term resistance training program. Marx et al. (2001) examined the long-term training (6month training regime) adaptations associated with a low-volume (circuit) resistance training program versus a peri-
odized, high-volume resistance program in college-aged women. The study found that subjects who followed the periodized, high-volume resistance program had higher levels of testosterone and insulin-like growth factor-1 (a muscle-building hormone) and lower levels of cortisol after 24 weeks of training compared with subjects who followed the circuit program. Greater increases in muscular strength, power and speed were also seen in the high-volume group. 

Smilios et al. (2003) examined the acute effects of the number of sets on testosterone, cortisol and growth hormone responses after a maximum strength protocol (5 reps at 88% IRM, 3-minute rest) and a muscular hypertrophy protocol (10 reps at 75% IRM, 3-minute rest). The subjects11 physically active young men with 2-8 years’ resistance training experience-performed 2, 4 and 6 sets of each exercise. Subjects also did 2 and 4 sets of a strength endurance protocol (IS reps at 60% IRM, 1-minute rest). In the muscular strength protocol, the number of sets did not affect the hormonal profile. In the muscular hypertrophy and strength endurance protocols, there was an increase in cortisol and growth hormone levels when 4 sets were performed versus 2. In this study, none of the testing conditions resulted in a significant increase in testosterone levels. Contrary to that finding, Kramer and Ratamess (2005) have summarized that protocols high in volume do tend to produce acute hormonal elevations in testosterone (as well as cortisol and growth hormone).

### Training to Failure Versus Not to Failure

In a unique study, Izquierdo et al. (2006) examined hormonal responses to 11 weeks of resistance training either to failure (one group) or not to failure (second group), followed by a 5-week peaking period involving a maximal strength and power protocol (identical for both groups). Subjects were 42 physically active males randomly assigned to the two groups. The results showed that 11 weeks of training to failure or not to failure resulted in similar gains in IRM strength, muscle power output of the arm and leg extensor muscles, and maximal number of repetitions in the squat. However, after the identical 5-week peaking period, the not-to-failure group showed greater increases in strength, power and resting testosterone levels and greater reductions in cortisol levels compared with the failure group. The failure group did show a greater increase in muscular endurance measured by bench press repetitions and a decrease in insulin-like growth factor 1.

### Rest Period

In a recent 6-month crossover study, Ahtiani et al. (2005) examined the effects of a shorter rest period (2 minutes) versus a longer rest period (5 minutes) during a strength training protocol that consisted of two heavy resistance training loading sessions per week for the lower

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**practical applications**

There are a number of ways in which trainers can use the research done on hormonal responses to resistance exercise when designing client programs.

**Energy Production.** During resistance exercise a cascade of events leads to an increase in several hormones that very specifically help deliver needed glucose to the working muscle cells for energy production. More energy results in greater work, which in turn yields greater force production. Therefore, from a hormonal perspective, personal trainers should encourage regular resistance training sessions each week.

**Training Volume.** Acute and chronic research shows that higher-volume resistance programs tend to elicit the greatest hormonal responses. Different training regimes, as accomplished with periodization models, are always encouraged in order to vary the resistance training stimulus and thus the muscular fitness benefits. For clients seeking greater muscle mass (hypertrophy), trainers should design programs that have greater volume; for example, by using multiple sets and/or multiple exercises for body areas.

**Training to Failure Versus Not to Failure.** Taking each set to failure when trying to increase muscular strength, power and hormonal response may not be as important a factor for clients as once felt. By taking each set to failure, a trainer may actually make clients more susceptible to overtraining and to decreased hormonal and muscle power adaptations.

**Rest Period.** Trainers are always working to create the most time-efficient workouts for their busy clients. Previous research (Kraemer et al. 1990) suggested that a shorter rest period (1 minute versus 3 minutes) elicited slightly higher acute hormonal responses. However, a newer study (Ahtiani et al. 2005) suggests that changes in strength, mass and hormone elevations do not differ significantly, whether the rest period is 2 minutes or 5 minutes.

**Concentric Versus Eccentric Training.** From the hormonal response perspective, trainers are encouraged to vary resistance training schemes to incorporate and emphasize concentric and eccentric training protocols.

**Force Versus Maximum Repetitions.** Training programs in which clients take sets to and beyond failure should be used in moderation. Always taking each set to failure can have negative effects on strength, power and hormone responses (Izquierdo et al. 2006). Then again, it appears that the more trained a client is, the greater the muscle-developing hormonal response will be when forced repetitions are periodically incorporated.
body. The subjects—13 recreationally trained men—trained for 3 months with either the short or the long rest period, and then they switched. Workout volume (reps x sets x weight) was equal in the two protocols. The study found that the length of the rest period did not affect the magnitude of change in subjects’ strength, mass or hormonal profile (testosterone, cortisol and growth hormone).

Concentric Versus Eccentric Training

During conventional resistance exercise, there is sequential concentric and eccentric muscle action. Durand et al. (2003) found that in training adaptations and hormonal responses, concentric muscle action produced more growth hormone than eccentric muscle action. These researchers used the same absolute load when comparing the two types of muscle actions. Of interest, however: in a study by Kraemer et al. (2006), which made the comparison using the same relative load, concentric and eccentric muscle actions produced similar growth hormone and testosterone responses.

Forced Versus Maximum Repetitions

Forced repetitions are a popular method for adding intensity to a resistance training program. Forced repetition’s are repetitions performed after a person has gone to failure. This type of training requires the assistance of a trainer (or workout partner). Performing maximum repetitions is synonymous with training to failure.

Ahtiainen et al. (2004) investigated the hormonal responses of forced repetitions versus maximal repetitions in eight male weightlifters (with several years of resistance training experience) compared with eight males who were not weightlifters (physically active but with no weightlifting experience). Although hormonal levels (testosterone, growth hormone and cortisol) increased with both training loads (in both groups), the testosterone increases in the experienced weightlifters were significantly greater from forced repetitions than they were from maximal repetitions. From maximal repetitions, the testosterone responses playa huge role, not just in immediate tissue remodeling and growth, but also in long-term strength, power and hypertrophy gains. Resistance exercise protocols that stress large muscle mass (i.e., that use multijoint exercises) and are high in volume and moderate to high in intensity tend to produce the greatest hormonal elevations, thus resulting in optimal muscular fitness benefits (Kraemer et al. 2005).

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