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Human Skeletal Muscle Hypertrophy

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ABSTRACT

It is well known that resistance training can induce substantial muscle hypertrophy. Longitudinal studies of four weeks to two years have been done to assess the effects of various resistance training protocols on muscle size. The majority of studies have been short-term (<20 weeks) and have used untrained subjects. Models of training commonly involve a single exercise using a high-repetition (≥8), low-moderate loads, and multiple sets (usually 3-5). The muscles most often examined are the elbow flexors and knee extensors. It is not clear that a best or optimal method of training exists. It is difficult to draw comparisons between many of these studies due to differences in training protocol, the subjects' training status, the muscle examined, and the method used to derive muscle size changes. Because of the paucity of data on trained subjects, future work should examine the adaptive response in these trained individuals. The use of high weight, low repetition as well as periodized training protocols need further examination. Furthermore, the existence of intermuscular differences in training response would suggest that not all training protocols elicit the same effect in different muscles. Sports Nutrition Review Journal (www.sportsnutritionsociety.org) Jan-Mar 1(1):1-13, 2004

Key Words: strength, muscle, exercise, muscle fiber

INTRODUCTION

This review is concerned with the effects of resistance training on skeletal muscle hypertrophy in humans. It is known that muscle fiber hypertrophy contributes in large part to muscle mass accretion seen with resistance training while muscle fiber hyperplasia plays a minor role (2, 4, 5, 8, 17, 45, 48). However, not all resistance training studies have been shown to produce gains in muscle mass, despite profound changes in various performance measures. For instance, Kramer et al. (38) examined the effects 14 weeks of resistance training which consisted of single-set, multiple-set, or periodized multiple-set training. Both multiple-set and periodized multiple-set training produced superior gains in dynamic maximal strength (i.e. 1-RM squat) in comparison to single-set training yet there were no differences between the groups with regards to body mass, fat mass, or fat-free mass. Conversely, it is possible that gains in muscle mass are not necessarily matched by gains in strength. Sale et al. (59) found that 19 weeks of lower extremity resistance training produced an 11% gain in knee extensor muscle cross-sectional area with no increase in maximal voluntary isometric knee strength or electrically evoked knee extensor peak torque.

It is evident that a large part of the adaptive response to resistance training is due to neural changes. The relationship between strength increases and changes in muscle cross-sectional area or muscle fiber cross-sectional area are tenuous (12, 15, 49, 57, 65). It is apparent that performance can change without changes in muscle mass. There is an abundance of literature which has examined the response of skeletal muscle to resistance training. The majority of these studies are short-term in duration (<20 weeks) and have used untrained subjects. Most of these studies have primarily examined only two groups of muscles: knee extensors and elbow flexors. It is known that training status has a profound effect on the subsequent adaptive response; furthermore, it is not clear that the adaptive response between muscles should be similar despite similar training protocols. Indeed, intramuscular differences in fiber composition and size exist in many muscles and would suggest that there may be a regional or non-uniform response to resistance training (36). A non-uniform response would further make it difficult to get a true assessment of how skeletal muscle adapts to resistance training

This review will focus on longitudinal studies that have measured changes in muscle cross-sectional area or muscle fiber cross-sectional area as result of resistance training. Only those studies which have derived data using advanced technology or techniques (i.e. magnetic resonance imaging, computed tomography, ultrasound, and muscle fiber biopsy) will be examined. This review will discuss the role of the following variables with regards to resistance training: training duration, training protocol, training status of subjects, inter-muscular differences, muscle and muscle fiber cross-sectional area measurements. It is these variables that likely have the greatest effect on the adaptive response to resistance exercises. For the purposes of this review, it is irrelevant whether gains in muscle mass are coupled to enhanced performance.

TRAINING DURATION

The majority of studies which have examined the upper extremity have ascertained the response of the elbow flexors and have used measures of muscle and muscle fiber cross-sectional area (CSA) to determine the pre- and post-training adaptations. It is apparent that training duration is not necessarily related to gains in muscle CSA. Narici and Kayser (51) had untrained subjects train for only 4 weeks with a resultant 17.7% increase in elbow flexor (biceps brachii + brachialis muscles) CSA. Conversely, Davies et al. (15) and Housh et al. (33) had subjects train for six and eight weeks, respectively without similar gains in elbow flexor CSA. The greater relative gains in elbow flexor CSA in the study by Narici et al. (51) may be due to the differences in training modality. Narici et al. had subjects perform isotonic contractions while Davies et al. and Housh et al. used isometric and isokinetic training, respectively. This would suggest a superiority of isotonic training over other forms of training with regards to muscle hypertrophy.

Roman et al. (57) trained elderly men for 12 weeks and this resulted in a 22.6% increase in elbow flexor CSA. The large gains in muscle CSA observed by Roman et al. (57) may be due to the fact that these were elderly men (~68 yr) who had no prior weight training experience and were "severely untrained." It would make sense that the more untrained an individual is, the greater the relative gains in muscle mass that could be accrued.

The vast majority of studies which have studied the lower extremity have examined the knee extensor muscles. Mayhew et al. (44) have shown that as little as four weeks of concentric or eccentric resistance training can produce a 12-14% (type I) and 18-26% increase (type II) in fiber CSA. Interestingly, concentric training produced greater relative gains in fiber CSA than eccentric training in this study when both groups trained at the same relative power level. One of the few patterns that one can observe with regards to fiber type changes are that type II fibers almost always enlarge relatively more than type I fibers; however, this does not seem to be related to the training duration.

For studies that have measured CSA of the thigh musculature, the gains in muscle mass ranged from 0%-23% with many of them less than 10%. Although the CSA of the vastus lateralis muscle increases by ~8-11% (18, 41) in as little as six to eight weeks, there are several studies of much greater length (16-19 weeks) which do not show larger gains and in some cases smaller gains. Nonetheless, only one month of training is required for young, healthy untrained men to make significant muscle mass gains in the upper and lower extremity muscles.

Unlike the majority of short-term studies, most of the data on skeletal muscle growth after long-term training is derived from biopsy data. It is evident that long training durations may translate into larger gains in fiber CSA depending on the fiber type. For instance, Donnelly et al. (16) found that 12 weeks of training the vastus lateralis muscle resulted in a 21.7% and 27.7% increase in type I and II fibers, respectively, in untrained middle-aged females. On the other hand, Staron et al. (63) found that 20 weeks of training the same muscle resulted in a 15.0%, 45.0% and 57.0% increase in type I, IIa and IIab+IIb fibers, respectively. So in this case, the longer training period resulted in greater gains in CSA of type II fibers but not type I fibers. In fact, many long-term studies show a tremendous increase in type II fiber size (39, 63, 56) while type I fiber size changes are either not significant or similar to changes observed after short-term training.

TRAINING PROTOCOL

A model of periodization posited by Stone et al. (66) divides training phases into the following categories: hypertrophy, strength, power, peaking, and active rest. The hypertrophy phase is characterized by high volume, low resistance exercise (ex. 3-5 sets, 8-20 repetitions or reps), the strength phase (3-5 sets, 2-6 reps), the power phase (3-5 sets, 2-3 reps) and the peaking phase (1-3 sets, 1-3 reps). The active rest phase varies for each athlete. Purportedly the major goal(s) of the hypertrophy phase of the training cycle are to increase muscle mass (hence the name) and to increase tolerance for resistance training thus laying the foundation for more intense training.

It should be apparent however that an examination of the various short-term training studies reveal that there is no clear "hypertrophy" training with regards to the sets and repetitions scheme delineated in this classical approach. Moss et al. (49) demonstrated that the training protocol which produced the greatest gains in elbow flexor CSA was neither the high-resistance nor low-resistance scheme. Roman et al. (57) used basically a protocol which more closely resembled the "strength" phase (3-5 sets, 2-6 reps) of a periodization scheme and these subjects experienced a profound increase in elbow flexor mass. Similarly, Davies et al. (15) used a "strength" protocol to induce significant muscle mass gains. In fact, if there is a pattern that can be seen with regards to the various training studies it is that investigators seem to "choose" high volume, low resistance training as the *modus operandi* for hypertrophy training.

A comparison of training volume while using the same resistance suggest that total work performed may affect muscle mass gains. Ostrowski et al. (55) found that both two or three sets (9-12 RM) were superior to one set (9-12 RM) with regards to gains in triceps brachii muscle mass, but there was no relationship between the gains in muscle mass and maximal strength (1-RM bench press). Moss et al. (49) compared various training volumes and loads on elbow flexor muscle CSA. Interestingly, these investigators controlled for the total electrical activity of the muscles to be trained. Electrical activity of the biceps brachii muscle was determined using surface electrodes on the short head of the muscle. Each group trained at either 90% 1-RM for two repetitions, 35% 1-RM for seven repetitions, or 15% 1-RM for ten repetitions (each group performed 3-5 sets). Oddly, only the 35% 1-RM group had an increase in triceps brachii muscle mass despite the fact that the strength increases was greatest in the 90% 1-RM group and least in the 15% 1-RM group. Thus, training load is ostensibly related to gains in strength but not gains in muscle size. It is apparent that forces as low as 35% of 1-RM can induce hypertrophy, albeit slight. The authors of the study suggested that the 35% 1-RM group performed more total work (70% and 45% more than the 90% and 15% 1-RM groups, respectively) than either group and the total amount of work may be a critical factor for muscle hypertrophy. Any attempt to draw conclusions as to the superiority of one training method over another with respect to muscle hypertrophy should not be based on measures of strength or power.

Similar to data on the upper extremity musculature, it is apparent that both high and low resistance training induce hypertrophy of the lower extremity muscles. Hisaeda et al. (31) compared a high volume-low load versus a lower volume-high load training regimen and found that neither method was superior to the other. Other work by Charette et al. (7) and Donnelly et al. (16) have demonstrated that high load-low volume training can induce significant muscle fiber hypertrophy. However, when using a higher repetition scheme, it is apparent that multiple sets are superior to a single set for inducing hypertrophy of the quadriceps and hamstring muscles (55, 62). In the investigation by Ostrowski et al. (55), the testosterone:cortisol ratio of the multiple set group decreased (nonsignificantly) suggesting a shift towards an overtrained state, yet these subjects had the greatest hypertrophic response. It is not clear if further training using multiple sets would have resulted in a cessation of muscle growth or perhaps even an atrophic response because of the decreased testosterone:cortisol ratio. It is evident that a decrease in the testosterone:cortisol ratio does not necessarily translate into a catabolic state.

Training protocols that involve a multiple-set, high repetition (>8 repetitions) scheme do consistently induce significant muscle and muscle fiber hypertrophy (especially of the type II fibers). It is difficult to ascertain if an "optimal" training regimen for hypertrophy exists because it is rare that the same training protocol is used when comparing one study to another. Although the majority of studies have used isotonic training, isometric training can also induce hypertrophy (1) while the effects of isokinetic training are inconsistent (10, 12, 33).

The majority of studies have also used a single exercise model to determine the effects of various training protocols on muscle size and strength. On the other hand, Kraemer et al. (37) and Ostrowski et al. (55) have used training protocols similar to those followed by bodybuilders. Kraemer et al. (37) used a model of periodization which involved alternating "hypertrophy" and "strength" workouts within the same week. Thus, subjects performed both high volume-low resistance and low volume-high resistance work for 17 different exercises. Ostrowski et al. (55) had subjects perform 21 exercises while varying the repetition scheme every 3-4 weeks for each group of subjects throughout the study; additionally, these subjects performed each set to failure.

Thus, for trained subjects it is apparent that a periodization scheme using multiple-sets, multiple exercises and a repetition scheme between 5-15 RM is efficacious for inducing hypertrophy. Whether this is the best or optimal method is unclear. The training protocol that is predominantly used for long-term training studies are non-periodized, multiple-set, high repetition ($\geq$8 repetitions) schemes (i.e., high volume-low/moderate weight). As stated previously, it is clear that this form of training results in significant muscle mass accretion.

TRAINING STATUS

The capacity of untrained subjects to undergo muscle hypertrophy after a resistance training program is well known. However, the degree that an individual is untrained could have an impact on the adaptive response. Individuals who are resistance-trained do not usually accrue the same relative gains in upper extremity muscle mass seen in untrained individuals (49, 55). Older individuals can experience skeletal muscle growth as a result of resistance training (13, 19, 26, 40, 61, 71); however, it is clear that their initially poor training status makes it relatively easy for them to accrue muscle mass. For instance, Fiatarone et al. (18) examined the effects of eight weeks of resistance training (i.e., knee extension exercises) on nonagenerians, whom one would suspect are severely untrained. These subjects not only increased quadriceps femoris muscle area but also the hamstring-adductor group despite the fact that the latter group of muscles was not directly exercised. Thus, in severely detrained individuals, muscles that act as stabilizers rather than prime movers or agonists can also increase in size.

However, McCall et al. (45) showed that trained individuals can make comparable gains in both elbow flexor and extensor muscle CSA as untrained subjects. This would lead one to question how training status is actually measured. Ostrowski et al. (55) operationally defined "trained" as subjects who could squat and bench press at least 130% and 100% of their body mass, respectively. This method at least provides a useful and objective method of determining an individual's training status. The use of questionnaires or no method at all for determining training status certainly has its limitations.

In fact, many of these trained subjects are "active" individuals who participate in resistance training for non-competitive purposes. On the other hand, Alway et al. (3) studied highly competitive male and female bodybuilders who had won their weight or height class at a national level competition and these subjects were perhaps among the most highly trained subjects that have ever been examined for a prolonged period. Using a form of periodized training in which these bodybuilders alternated between heavy and light weights, 24 weeks of training resulted in small but non-significant increases in type I and II fiber CSA; however, elbow flexor mass did increase significantly. A close examination of the individual data for each bodybuilder indicates, however, that there can be large differences in training response between subjects. Although the majority of the subjects had an increase in elbow flexor CSA of ~8%, one subject had a 11.7% decrease, another had only a 3.3% increase, while the greatest increase was found to be 19.2%. Thus, despite the same training protocol, individual differences due in part to genetics, diet, drug use, and other factors may contribute to the variable response to training.

Long-term training of initially untrained subjects results in increases in muscle and muscle fiber CSA (22, 23, 25, 39, 42, 43, 52, 53, 63, 68). An examination of trained subjects reveal that enlargement of type II fibers (with no significant change in type I fibers) can occur with explosive-type strength training (23, 68); however, hypertrophy is greater with conventional heavy resistance training than with explosive training (22, 68).

In an extensive investigation that spanned one to two years, Hakkinen et al. (24, 25) examined the response of elite weightlifters. One and two years of training were found to result in non-significant increases in mean fiber area of 3.9% and 5.9%, respectively. Thus, it seems that after reaching an elite level of bodybuilding or weightlifting, significant gains in muscle mass are difficult to acquire. Nonetheless, an augmentation of muscle mass, albeit a small one, can occur in well trained resistance trained athletes.

INTERMUSCULAR DIFFERENCES

In the upper extremity, the triceps brachii muscle ostensibly has a greater hypertrophic response than the elbow flexors (i.e. biceps brachii + brachialis muscles) (33, 36, 45). The study by McCall and co-workers (45) was intriguing in that the training program consisted of various exercises which targeted each major muscle group with four exercises that emphasized the elbow flexors. Yet, the triceps brachii muscle had twice the gain in muscle cross-sectional area than either the biceps brachii alone or in combination with the brachialis. Housh et al. (33) also showed that the triceps brachii muscle had a greater hypertrophic response than the elbow flexors after eight weeks of isokinetic training.

The most frequently studied muscle in the lower extremity is the vastus lateralis or the quadriceps femoris muscle group. Vastus lateralis CSA can increase up to ~12% although most short-term studies demonstrate increases usually >10%. This response is less than that observed in the muscles of the upper extremity. Similarly, the rectus femoris makes gains in CSA similar to the vastus lateralis. Albeit one study showed much greater gains in muscle thickness in the vastus intermedius versus the rectus femoris (70). Alway et al. (1) found that the soleus muscle fibers enlarge proportionately more than the medial or lateral gastrocnemius.

Housh et al. (33) performed an extensive study which they measured the CSA of multiple regions of the anterior and posterior muscles of the thigh. This study exemplifies the difficulty in determining the “true” hypertrophic response of various muscles. It is evident that within the quadriceps femoris muscles, the rectus femoris enlarges relatively more so that any of the vasti muscles at all levels (i.e., proximal, middle, and distal sections). However, when comparing the different cross-sections, the rectus femoris and the vastus lateralis increased greatest in the distal section, the vastus medialis in the middle section, and the vastus intermedius increased similarly throughout all sections. Regional differences in muscle size were also seen in the hamstring group.

Few long-term studies have looked at intermuscular differences in the muscle hypertrophy. The brachialis muscle responds with relatively greater growth than the biceps brachii in response to 20 weeks of training young men and women (53, 54) and 24 weeks of training in elite bodybuilders (3). Narici et al. (52) found that 26 weeks of training the leg extensors resulted in greater growth in the rectus femoris muscle versus the vasti muscles.

It is clear that there are inter- and intramuscular variations in the hypertrophic response to skeletal muscle. These differences may be due to differing nerve supplies, genetic influences, muscle anatomical/architectural considerations or exercise training. It is apparent that muscle growth is not the result of uniform growth within a muscle or muscle fiber. In fact, studies that have examined changes in muscle cross-sectional area and fiber cross-sectional area have produced conflicting results (19, 57).

MUSCLE AND MUSCLE FIBER CROSS-SECTIONAL AREA

A comparison of fiber CSA and muscle CSA derived from the same muscle reveal that each measure has its limitations. For instance, resistance training of the elbow flexors produced a 24% increase (non-significant) in type I fiber CSA of the biceps brachii, a 37% increase in type II fiber CSA, a 23% increase in the elbow flexor (biceps brachii + brachialis) cross-sectional area, and a 14% increase in elbow flexor muscle volume (57). Frontera et al. (19) reported a 10.6% increase in quadriceps CSA yet type I and II fiber CSA of the vastus lateralis increased 33.5% and 27.6%, respectively. On the other hand, McCall et al. (45) found that the biceps brachii muscle CSA increased 12.6% while type I and II fiber CSA increased 10% and 17.1%, respectively. From this data, it is evident that both muscle and muscle fiber CSA do not reflect the true growth of the muscle (i.e. muscle volume). Yet, only one study reported in the literature had measured muscle volume (57). Future investigations should include measures of muscle volume or multiple cross-sectional area measures of the involved muscle and multiple biopsy sites for a more accurate picture of a muscle's adaptive response.

The majority of studies show that type II fibers grow relatively more than type I fibers. This would suggest that type I fibers do not have the same capacity as type II fibers for hypertrophy, or alternatively, the training programs typically utilized may not be the best method of induce type I fiber growth. For instance, because type I fibers have a high endurance capacity, would performing high repetition work (ex. 20-30 repetitions) be more conducive to type I fiber enlargement? Elite cyclists and distance runners display type I fibers in the vastus lateralis and gastrocnemius with CSAs that are larger than those seen in strength-power athletes (11, 21). However, one should remain cognizant of the fact that having large muscle *fibers* (as determined from a single biopsy) may not necessarily translate into a large muscle.

Is it possible to induce maximal hypertrophy of type I and II fibers via a combination of heavy resistance-low volume and light resistance-high volume training? Jackson et al. (35) had college age men perform a 7.5 weeks strength training (heavy weight, low repetition) and 7.5 weeks of muscular endurance training (low weight, high repetition) with a 5.5 week hiatus in-between. One group performed the strength program followed by the endurance program while a second group trained in the reverse order. In both groups, regardless of the type of exercise, increased muscle fiber CSA of type I, IIa, and IIb. Subjects who performed strength training during the second phase demonstrated further growth in type I and IIb fibers. On the other hand, those who performed endurance exercise during the second phase experienced a decrease size in all fiber types. Since these subjects were initially untrained, it would seem plausible that either form of training might induce muscle fiber growth. However, once each subject was "trained" (i.e. after the first 7.5 weeks of training), it is evident that endurance exercise might have a detrimental effect on muscle fiber size.

Long-term studies which examined both muscle and muscle fiber CSA changes demonstrate no clear relationship between the two measures. Narici et al. (52) found a 19.5% increase in vastus lateralis cross-section while mean fiber area increased 1.9%. Elite female bodybuilders had a non-significant increase of ~9.0% of mean fiber CSA while the biceps brachii CSA decreased 2.1% (3). On the other hand, elite male bodybuilders demonstrated a ~1.6% increase in mean fiber CSA (of the biceps brachii) coupled with a slightly larger (3.6%) increase in biceps brachii CSA (3). It should be evident that the reliance on single muscle biopsy data does not accurately represent the adaptive response of the entire muscle.

STATISTICAL VS PHYSIOLOGICAL SIGNIFICANCE

Both short-term and long-term training usually result in significant muscle growth. There is a preferential hypertrophy of type II over type I muscle fibers. In fact, several studies have shown that type I fibers increase, but not significantly ($P>0.05$) (1, 3, 22, 23, 39, 53). It should be emphasized however that a lack of statistical significance does not mean changes are not physiologically significant or meaningful. Small sample sizes often preclude reaching statistical significance. However, an examination of individual data points can provide telling information in that a large change in one individual may be masked by little or no change in other individuals when examining grouped data. Certainly, one should not expect all subjects to respond identically.

For a well-trained athlete, increases of 1-2% can represent a meaningful difference physiologically. In fact, the investigation by Alway et al. (3) demonstrated precisely how variable the response are between individuals (i.e. one male bodybuilder had a 19.2% increase while male bodybuilder had a 11.7% decrease in elbow flexor CSA). It would seem unreasonable to conclude that a 19.2% increase in elbow flexor CSA is not physiologically meaningful based on grouped data showing no statistical significance.

SUMMARY AND FUTURE DIRECTIONS

There is an abundance of longitudinal resistance training studies in the scientific literature. The majority of them are short-term (<20 wk) and have examined either the elbow flexors or the knee extensors. With untrained subjects, training for as little as 4 weeks can induce significant increases in muscle CSA; however, a longer training duration does not necessarily translate into a proportional increase in muscle mass. In trained subjects, the evidence suggests that gains in muscle mass are much more difficult to acquire. Perhaps with elite athletes, incorporating a periodization training scheme may be warranted.

The training protocols used most often in resistance training studies are high-volume, low-resistance (i.e. 3-5 sets, $\geq$8 repetitions). In fact, this training scheme is commonly referred to as “hypertrophy” training (cite Stone’s piece). It is evident that “lower-volume, higher-weight” training can induce similar hypertrophy despite the fact that this scheme of training is commonly referred to as “strength” training (as one phase in a series of phases in a periodization scheme). Thus, it is the opinion of this author that these designations (i.e. “hypertrophy” or “strength” training) are inaccurate. Because of the poor relationship between gains in muscle mass and performance, it is clear that any attempt in making a distinction between phases of training as either growth-enhancing or strength-enhancing is arbitrary. Both forms of training result in muscle mass accretion and strength gains. Nevertheless, the high-volume, low-resistance training protocols that are used by the majority of investigators do in fact result in substantial muscle hypertrophy. Whether this is the best or optimal method of training is not clear.

With regards to specific muscles, the current evidence suggests that in the upper extremity, the triceps brachii enlarges proportionately more the elbow flexors (i.e.

biceps brachii and brachialis). In studies which have compared the various thigh muscles, the rectus femoris seems to enlarge proportionately more than the three vasti muscles. Based on the few studies that have examined intermuscular differences in the training response, the evidence would suggest that not all muscles respond similarly to training. Within the same muscle, it is apparent that muscle growth is non-uniform. This would lead one to question the accuracy of single measures (muscle CSA or muscle fiber CSA) used in the majority of studies.

Future work should attempt to make multiple measurements of muscle or muscle fiber CSA. Muscle volumes (estimated from serial muscle CSA measurements) would provide the most accurate indicator of the training response. Longer duration training studies should be emphasized using trained subjects since the applicability of the majority of existing studies are for untrained individuals. The various training protocols that have been used for many of these studies are not identical although there are common elements between them. That is, the use of high volume training (ex. 3-5 sets, >8 repetitions) has been shown to produce consistent increases in muscle and muscle fiber CSA. Although not used as frequently, the use of lower volume, high resistance (ex. 3-5 sets, <8 repetitions) protocols can produce similar increases in muscle size. It is not evident that high volume training is superior or inferior to lower volume training. In essence, both are effective training protocols. One could reasonably speculate that because of biological variability certain individuals might respond more favorably to high volume (or low volume) training with regards to muscle hypertrophy.

The inter- and intramuscular variation in the hypertrophic response warrants further examination. Based on the available evidence, I would posit that not all muscles have the same capacity for muscle hypertrophy and therefore should not be trained identically. For instance, anecdotal reports as well as personal communication with many bodybuilders suggests that the gastrocnemius muscle is much more resistant to training-induced growth whereas the muscles of the torso (ex. pectoralis major) seem to respond quite easily. This difference may be due to various factors that include: type of training involved, muscle architecture, genetics, concentration of androgen receptors, fiber composition, etc.

Whether a “best” method of hypertrophy training exists is highly debatable. The fact that many disparate stimuli such as chronic stretch, intermittent stretch, overloading via surgical ablation, and various exercise protocols can induce substantial muscle growth would indicate that there are many ways of inducing hypertrophy. Also, what seems to work well for untrained individuals may not be applicable to the trained or elite athlete. Perhaps if a best method exists, it would be one in which an individual incorporates different forms of training (ex. high volume - low resistance, low volume - high resistance, eccentric loading, ballistic training, etc.) as part of an overall training regimen that emphasizes multiple-joint, large muscle mass, heavy resistance exercises.

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