MUSCLE HYPERTROPHY

THE COMPLETE EXERCISE GUIDE

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02

Muscle Size: How Much Muscle Can You Gain?

When you begin a resistance training program in the gym, with the goal of increasing your muscle size, it is natural to think about how much muscle growth is achievable over time. You may have images of your favorite fitness influencers, bodybuilders or athletes in mind. Accordingly, you may have the desire to acquire large amounts of muscle mass, or you may worry about gaining too much muscle and achieving a look that is non-desirable. It is common for individuals to have a grasp on what changes in weight should look at over time. For example, a weight loss or weight gain goal is quite tangible to most individuals (you look at the scale). On the other hand, If you were asked how much muscle growth is possible in your quads or biceps over a training career, it would be more difficult to come up with an answer. Admittedly, there is no consensus on how much muscle growth is possible over a lifting career. However, training interventions and time-course studies have provided us with data which may help to guide our expectations. This chapter will discuss limitations on human skeletal muscle growth with training and provide certain expectations of what muscle growth may look like over time.

Is Muscle Growth Limited?

It is interesting to think about how many years into lifting skeletal muscle growth plateaus. For example, if you have been lifting weights for 10 years, are you still growing when you go to the gym? Or, are you simply providing a stimulus to stimulate muscle protein synthesis and upregulate signals that maintain your muscle size? This is important to think about because muscle growth is not likely infinite. Some scientists have made the suggestion that the majority of muscle growth appears to happen in the first several months of training [1], with a plateau observed as early as 3 months into training. Although the majority of growth may occur relatively early I don't believe that we stop growing until many years into a lifting career. However, it does appear that muscle growth begins to accrue at a much slower rate once you become more "trained". For example, a 6-month resistance training study in non-resistance trained women found that the arm cross-sectional area increased around 11% following the first 3-months of training and only 6% in the following 3-months of training [2]. This may represent a slowing of muscle growth as individuals reach their growth potential. On the other end of the spectrum, a study from 1987 [3] examined muscle size and strength changes in thirteen elite weightlifters over an entire training year. Following a year of training, authors observed that body mass, thigh girth, body fat percentage and muscle fiber size did not change significantly [3]. All of the athletes included in this study were Finnish champions and/or Finnish national record holders, suggesting they were advanced in their lifting careers [3]. Of course, it could be argued that elite weightlifters are not training specifically for muscle growth; however, it is still interesting that their training did not lead to some meaningful growth over an entire year. Perhaps bodybuilders can provide more useful insight regarding limitations on skeletal muscle growth given their primary training pursuit is the acquisition of new muscle tissue? A study from 1992 [4] examined changes in muscle cross-sectional area and muscle fiber size following 24-weeks of training in 5 male and 5 female competitive bodybuilders. The training program they performed had a great deal of biceps work, including barbell curls, standing alternating dumbbell curls, barbell scott curls, bent over dumbbell concentration curls, and hammer curls [4]. Following the 24-week period, authors observed no changes in muscle fiber size, muscle fiber number or muscle cross sectional area [4]. Ultimately, the authors concluded that after reaching a high level, improvements in muscle characteristics may be minimal [4]. It seems reasonable to suggest that this data provides some evidence that muscle growth is limited to some finite limit. Individuals who have reached a competitive level do not appear to grow in a meaningful way that can be measured across the short durations seen in research interventions. The idea that muscle growth is limited is also rooted in logic. It would not benefit longevity to endlessly seek more and more muscle tissue. In a sense, limits on muscle growth may serve as a protective mechanism from excessive amounts of muscle tissue that would be very energetically costly. In addition, metabolic theories of aging [5], and stress research [6,7]) may provide a rationale as to why large amounts of muscle tissue may not be beneficial for overall longevity.

An interesting study in rodents may help to illustrate the finite capacity of muscle growth. Yes, rodent studies don't translate perfectly to humans, but they can still teach us interesting concepts and help us think in new ways about various physiological systems. A study by Hamilton et al. [8] employed a technique known as synergistic ablation. Synergistic ablation is a technique where they surgically remove the gastrocnemius and soleus muscles of the calf musculature. This leaves the remaining muscle (the plantaris) responsible for the entire burden of supporting the rodent's weight (known as functional overload). Since the one muscle is now bearing the full burden of the rodent's weight that the gastrocnemius and soleus used to help support, the muscle is "overloaded" (similar to lifting weights). As you might imagine, you can't just teach a rodent to squat or perform various resistance training exercises. Thus, this model has proven helpful for providing a hypertrophic stimulus in rodent research. One interesting characteristics of this model is that the plantaris rapidly grows to compensate for the lack of other musculature. For example, Hamilton et al. [8] observed an 81% greater size in plantaris muscles following synergistic ablation compared to control muscles following 21 days. Thus, this model may represent an exaggerated and extreme model of muscle growth. Put another way, the muscle would not grow by 81% from voluntary exercise over this time-period even if the rodents could lift weights. Thus, the growth observed can be considered rapid and unusually robust. This study by Hamilton et al. [8] was interested in intrinsic mechanisms within the muscle that would try to slow and limit this rapid growth. Thus, the authors examined the stimulation of muscle growth (activation of certain proteins within the muscle that tell it to grow), but also looked at negative regulators of muscle growth (factors working against the stimulation of muscle growth). The authors referred to these mechanisms as "molecular breaks". Through their study, the authors identified that there appeared to be 3 separate molecular breaks that were working against muscle growth and ultimately concluded that the rate of muscle growth is tightly regulated even when faced with a supra-physiological stimulus such as synergistic ablation [8]. What does this mean? This shows that the muscle may possess an ability to limit excess growth at the molecular level. Further, it seems reasonable to assume that there are inherent mechanisms within our physiology that protect us from becoming too large by limiting our muscle growth. If muscle growth limits do exists in humans, it may first be helpful to discuss what muscle growth looks like.

Changes in Muscle Size with Training

When looking at individual muscle groups, the scientific literature offers insight into only a few select muscles. For example, there are several studies that have looked at biceps muscle growth. Although this is not the most exciting muscle group, from the researcher perspective it offers a lot of positives! The biceps are an easy muscle group to image using ultrasound. Thus, researchers are able to measure really small changes over an 8-12 week time period with confidence. Another positive aspect when it comes to studying the biceps is that you do not have to worry about swelling in the muscle as much as you might in the lower body. If an individual is visiting a lab for a study, they have likely walked across a college campus to arrive at that lab. Walking will cause muscle contraction, which can cause muscle swelling in the lower body. This could possibly be confused with muscle growth, which may confound the actual findings of the study. Because of these reasons, many labs have opted to use the bicep for research to learn about various training interventions. With that being said, there are many studies that do measure changes in the quadriceps muscles following training interventions. This muscle group is, in general, a bit more difficult to image an measure compared to the biceps, but many labs have perfected their skills, allowing insight into lower body growth.

When muscle growth is discussed in the subsequent sections, It will be discussed in terms of muscle thickness in centimeters (cm). Figure 2.1 provides an example image of a biceps muscle thickness and figure 2.2 provides a representative image of the quadriceps muscle thickness taken using B-mode ultrasound. A measurement of muscle thickness represents the thickness of the muscle from the muscle-bone interface (where the muscle meets the bone) to the muscle fat interface (there the muscle ends and fat begins). Imagine you are peering down into your muscle through your skin and fat. After skin and fat, you come to the muscle which sits over the bone. There are other ways to measure muscle, but B-mode ultrasound is by far the most commonly used method within the scientific literature (MRI or CT scan would be gold standard, but are much more expensive). A gym technique that may be employed to measure muscle growth would be arm circumference. Interestingly, muscle growth can occur without a change in arm circumference. Thus, muscle thickness through imaging is considered a much more sensitive tool for the detection of muscle growth. The following sections will discuss common changes in muscle thickness observed in the biceps and quadriceps muscle groups.

Figure 2.1 - Biceps Muscle Thickness Image Using B-mode Ultrasound

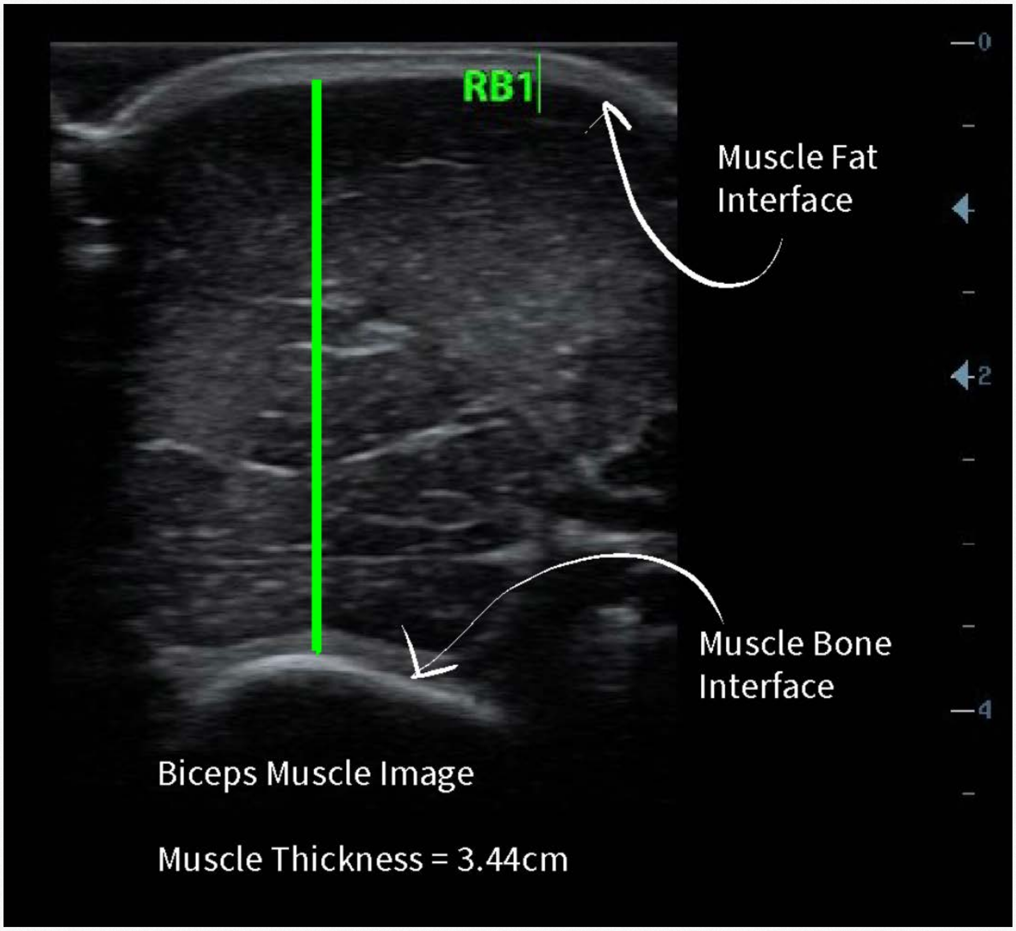

Figure 2.1 displays a B-mode ultrasound image of the biceps. Within the image, the muscle fat interface and the muscle bone interfaces are labeled. The Green line represents how muscle thickness is measured (from interface to interface). The biceps image provided is a female biceps with a thickness of 3.44cm.

Figure 2.2 – Anterior Thigh Muscle Thickness Image using B-mode Ultrasound

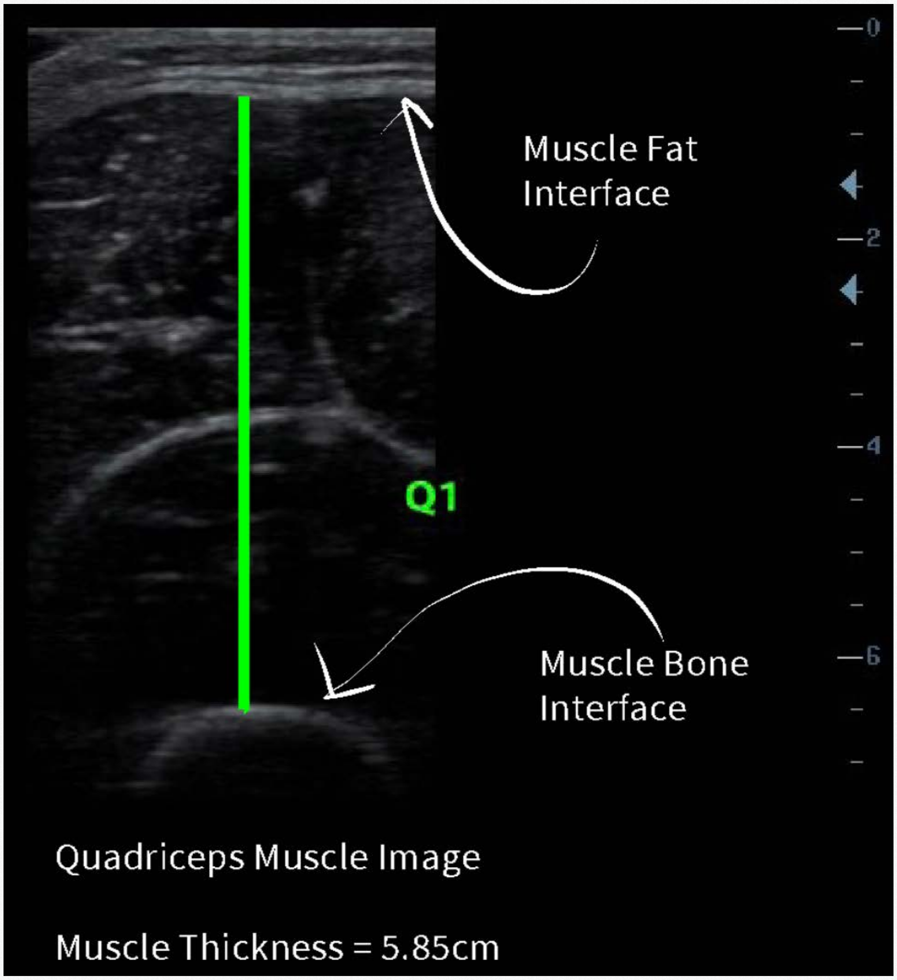

Figure 2.2 displays a B-mode ultrasound image of the quadriceps muscles. Within the image, the muscle fat interface and the muscle bone interfaces are labeled. The Green line represents how muscle thickness is measured (from interface to interface). The biceps image provided is a female biceps with a thickness of 3.44cm.

Upper Body Growth in Non-Resistance Trained Individuals

When considering the biceps muscle, it would be common to see biceps with a muscle thickness between 2.0-4.0 cm. When looking at changes in muscle thickness in untrained individuals in the upper body (biceps), it seems that growth in the magnitude of 0.2 cm in biceps muscle thickness can be expected over an 8-12 week time period. When reading a research paper, this 0.2 cm change would represent the average change across all participants. Thus, we would expect that some individuals could gain a little more and some individuals would likely gain a little less than 0.2 cm of muscle thickness following a short resistance training intervention. To provide some examples, Buckner et al. [9] observed a change of 0.16 cm in the thickness of the bicep following 8 weeks of biceps curl training (4 sets at 70%1RM to failure) in untrained individuals. If we consider the average thickness of the bicep is between 2.0-4.0 cm, this would represent a 4%-8% increase in muscle thickness over 8 weeks. If you are trying to imagine what this looks like, it may be helpful to take out a tape measure and see how large 0.16 cm (or 1.6 millimeters) looks. Such a change is able to be measured using ultrasound, but it would not necessarily be visually apparent when looking in a mirror. Similar to this study, Counts et al. [10] examined biceps muscle growth in the magnitude of 0.14-0.17 cm over a 6 week time period in non-resistance trained individuals performing biceps curls 3x/week (4 sets to failure at 70% 1RM). This is not too unlike the findings of Bottaro et al. [11] who examined a 0.17-0.2 cm increase following 12 weeks of training in non-resistance trained young men. In this study, individuals trained 2x/week and performed biceps curls for either 3 sets of 8-12 reps or 1 single set of 8-12 reps. Interestingly, muscle growth in this study was similar regardless of the volume of exercise performed. To provide one additional example in untrained individuals, Abe et al. [12] examined changes in biceps muscle thickness following 12 weeks of individualized (1 set or 3 sets) resistance training in non-resistance trained middle aged adults (25-50yrs). Participants trained 3x/week over the 12 week time period. The program included several exercises (knee extension, knee flexion, chest press, seated row, elbow flexion, and elbow extension exercises) and participants performed 8-12 repetitions to fatigue for each exercise set. Following the intervention, authors found that males increased muscle size by 0.47cm (~15% increase) and females increased muscle size by 0.32cm (~17% increase). These changes in muscle size are a bit higher than the other studies, and may represent the higher end of what might be possible over an 8-12 week time period? Thus it may be able to increase muscle thickness as much as nearly half a centimeter for some individuals over a 12 week period. However, changes in the magnitude of 0.2 cm would appear much more common.

Upper Body Growth in Resistance Trained Individuals

In resistance trained individuals it is usually agreed that muscle growth lessens over time. Meaning, robust growth is often observed in non-trained individuals, but if you have been lifting for a number of years, it may be more difficult to simulate a growth response. In 2020 a study observed a 0.17 cm increase in biceps muscle thickness following 8-weeks of twice a week biceps curl training (4 sets of 8-12RM)[13]. This value is not unlike some of the changes that have been observed in untrained individuals. Thus, with focused training it appears that previously resistance trained individuals are capable of additional muscle growth. Looking at other studies, Schoenfeld et al. [14] observed changes of 0.07, 0.2 and 0.29 in their 1 set, 3 sets and 5 sets training conditions respectively following 8 weeks of resistance training. Interestingly, their moderate and high volume conditions (3 sets and 5 sets per exercise per session) observed similar biceps growth (in some cases greater) as other studies despite having no direct biceps work. Meaning, the only biceps training came indirectly from wide grip lateral pull down exercise and seated cable row. It is quite interesting that their 5 sets of indirect work resulted in a higher magnitude of growth than the aforementioned paper that employed 4 sets of direct biceps curls to failure over the same time span (this will be discussed in greater depth in chapter 3). However, it may be possible that indirect training with enough volume may stimulate robust skeletal muscle growth. Either way it is interesting to entertain the possibility that such muscle growth was observed despite no inclusion of biceps curls within the training program. Another paper by the same authors observed changes in biceps muscle thickness in the magnitude of 0.43 cm in resistance trained individuals following 8-weeks of resistance training. Much like their previous investigation, this training study had individuals perform indirect biceps training via a close grip lateral pull down and a seated cable row. Authors had 2 volume-matched training conditions that completed 3 sessions per week of 7 sets of 3RM (heavy weight with low repetition) or 3 sets of 10RM (relatively lighter weight with more repetitions). This very large magnitude of growth is difficult to reconcile given what is typically seen in trained individuals. However, when you look at the authors methods, they used A-mode ultrasound instead of B-mode ultrasound. Unlike B-mode, A-mode does not allow live imaging of the muscle tissue [15]. It has been pointed out that this method may have several limitations when measuring muscle growth, particularly since the technician may have greater difficulty discerning key landmarks within an image (i.e. muscle-fat interface and muscle-bone interface)[15]. Overall, it seems that resistance trained individuals can gain 0.1-0.3 cm of additional muscle thickness in the biceps over a short period of training. One study suggested larger changes, but the measurement tool may have led to an exaggerated response.

Lower Body Growth in Non-Resistance Trained Individuals

When looking at the lower body musculature, muscle thickness values are typically larger compared to the biceps. For example, it would be common to see quadriceps with a muscle thickness between 4.0-6.0 cm. Abe et al. [12] examined muscle growth adaptations (measured at 30% the distance from between the lateral condyle of the femur and greater trochanter of the leg for reference) following 12 weeks of full body training in non-resistance trained middle aged adults (25-50yrs). Participants trained 3x/week over the 12 week time period. The program included several exercises (knee extension, knee flexion, chest press, seated row, elbow flexion, and elbow extension exercises) and participants performed 8-12 repetitions to fatigue for each exercise set. Following the exercise intervention authors observed that muscle thickness had increased from 6.12 cm to 6.4 cm in men (mean change of 0.28 cm) and from 5.15 cm to 5.28 cm (mean change of 0.13 cm) in women. This change in muscle size seems comparable in magnitude to changes that have been seen in the biceps over a similar period of time.

Figure 2.3

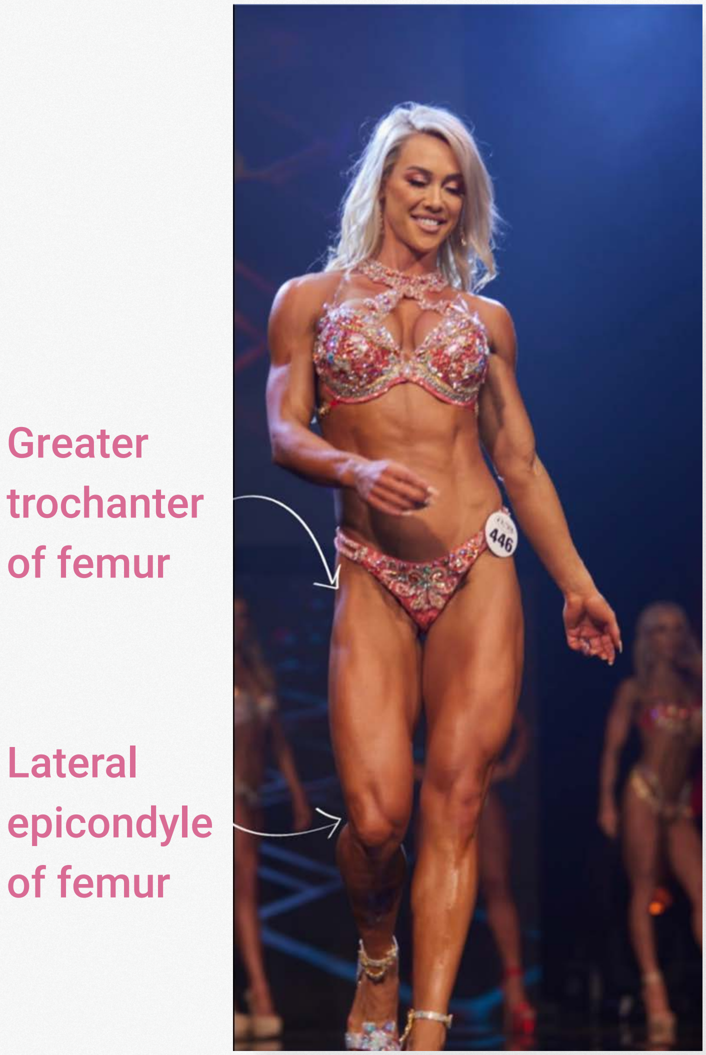

Figure 2.3 displays anatomical landmarks used to determine where muscle thickness will be measured in the lower body. In this example, the approximate sites of the greater trochanter and lateral epicondyle of the femur are indicated. Other studies may use the lateral epicondyle of the tibia, which is located slightly below the lateral epicondyle of the femur.

When looking at other studies in untrained individuals, Starkey et al. [16] examined muscle growth adaptations (20% the distance between the greater trochanter and the lateral epicondyle of the tibia) following 14-weeks of training 3x/week where individuals performed 1 set per exercise or 3 sets per exercise. Participants performed 8-12 repetitions to fatigue for both the knee extension and knee flexion exercise. The 3 set group demonstrated an increase from 5.5 cm to 5.61 cm (mean change of 0.11 cm) and the 1 set group increased from 5.71 to 5.74 (mean change of 0.03 cm). Neither of these changes reached statistical significance. Thus it appears that their overall method was ineffective when looking at this particular area of growth. Avelar et al. [17] examined changes in muscle thickness of the mid-thigh (measured 15 cm above the upper border of the patella) following 6-weeks of training in non-resistance trained men. The authors had one condition that performed their multi-joint exercises before single-joint (MJ-SJ) exercises and another group that performed single-joint exercises before their multi-joint exercise (SJ-MJ) [17]. Both groups trained 3 times per week and performed 10 exercises (3 sets of 8-12 reps per set). The exercises included in the program were: bench press, lat pulldown, upright row, shoulder press, triceps pushdown, arm curl, leg press, knee extension, leg curl, and calf raise. All exercises were performed to volitional failure. Following the intervention, the MJ-SJ condition increased muscle thickness from 3.48 cm to 3.73 cm (mean change of 0.25 cm) and the SJ-MJ condition increased muscle thickness from 3.57 cm to 3.71 cm (change of 0.14 cm)[17]. Altogether, there seems to be a somewhat consistent pattern of changes in muscle thickness somewhere between 0.1 and 0.3 cm following 8-12 weeks of training in non-resistance trained individuals.

Lower Body Growth in Resistance Trained Individuals

When examining lower body growth in resistance trained individuals, Jakubowski et al. [18] examined changes in muscle thickness of the vastus lateralis (50% of the distance between the greater trochanter and the lateral epicondyle of the knee) in resistance trained men following 12-weeks of full body resistance training combined with either whey + leucine supplementation or whey + hmb supplementation. The program included the following exercises: squat, bench press, deadlifts, dumbbell shoulder press, pull-ups/dips, bent over row, biceps curls/lying triceps extensions, with leg press and close- grip bench press performed in weeks 9 and 10 [18]. The authors observed no difference between their respective supplement conditions; thus these data can help us to frame realistic expectations of muscle growth over time. They observed changes of 0.1 cm and 0.2 cm in the leucine and hmb supplementations conditions respectively. This seems similar to some of the previously mentioned changes observed in untrained individuals. Amirthalingam et al. [19] examined changes in anterior thigh muscle thickness (50% between the inguinal fold to the superior margin of the anterior surface of the patella) following 6-weeks of resistance training. The authors included a 5 set training group and a 10 set training group. The groups performed a "split routine" where the 1st targeted chest and upper back (flat bench press, incline bench press, lat pull-down, seated row), the 2nd session focused on the legs (leg press, lunges, leg extension, leg flexion, calf raises), the final session focused on shoulders and arms (shoulder press, upright row, bicep curls, triceps push-down). The 10-SET group performed 10 sets of 10 reps for the first 2 compound exercises at every training session, while the 5-SET group performed 5 sets of 10 reps for the first 2 exercises at every training session. All participants performed 3-4 sets of the remaining accessory work. Relative loads were set between 60-80% 1RM. A whey protein supplement (30.8 g of protein, 0.2g of fat, and 0.9 g of carbohydrates) was provided to participants 30 minutes post-exercise. Following this intervention, authors observed that the anterior thigh in the 10 set group increased from 5.33 cm to 5.44 cm (mean change of 0.11 cm). In the 5 set group, muscle thickness increased from 5.31 cm to 5.57 cm (change of 0.26 cm). All of these changes in muscle thickness are within a similar range and suggest that resistance trained individuals can achieve muscle growth increases in the range of 0.1-0.3 cm over an 8-12 week time period.

Extraordinary Findings

Despite the suggestion that muscle growth tends to be rather small over an 8-12 week time period. It is worth pointing out a few extraordinary findings. For example, Schoenfeld et al. [20] examined muscle growth in the anterior quadriceps (50% of the distance between the anterior superior iliac spine and the superior border of the patella) following 8-weeks of training with long interest rest (3 minutes rest between sets) or short interest rest (1 minute rest between sets). Participants trained 3x/week and completed 8-12 repetitions to failure per set. 7 exercises were included in the program (barbell back squat, plate-loaded leg press, plate-loaded leg extension, flat barbell press, seated barbell military press, wide-grip plate-loaded lateral pulldown, and plate-loaded seated cable row). Participants were also give a protein supplement on training days (24 g protein). Following the intervention authors found that the anterior thigh muscle thickness increased from 5.21 cm to 5.61 cm (mean change of 0.36 cm) in the short rest condition and increased from 5.35 cm to 6.06 cm (mean change of 0.71 cm) in the long rest condition. The change (particularly the change in the long rest, higher volume training condition) is 3-4x the magnitude of what is observed in other studies. Another study from the same research group examined the influence of exercise volume while implementing a similar resistance training program (same exercises as previous study). Authors had resistance trained males perform either 1 set, 3 sets or 5 sets per exercise (per session) over an 8-week period. They trained 3x/week and observed increases of 0.68 cm in the muscle thickness of the rectus femoris and 0.72 cm in the muscle thickness of the vastus lateralis in their high volume training condition over the time period. These rather large changes are difficult to reconcile in the context of the scientific literature. To the masses, the final conclusion is typically all that gets communicated (what you'll read in the abstract, i.e., "long rest is superior to short rest for growth" or "high volume is superior to moderate volume for muscle growth"). However, when you look at the data it becomes more difficult to draw a strong conclusion.

It is unclear what exactly, about these studies resulted in such a large magnitude of muscle growth. It is possible that the high volume performed in both of these studies lead to excess muscle damage and inflammation that was mistaken for muscle growth. Alternatively, it is possible that performing 5 sets per exercise leads to muscle growth of a very large magnitude (compared to 1 set or 3 sets per exercise per session). However, this seems unlikely considering other studies have performed what seems to be comparable volumes and training programs and not observed such large increases [18,19]. This is really important to consider as popular social media influencers have made posts suggesting "3-5 minutes rest is better for hypertrophy" or made the suggestion that "volume load is the most important factor for stimulating growth" based on the papers such as these. This conveys a message that the entire scientific community has closed the book on a topic and conclusively proven a certain concept. For example, I have seen half-a-dozen posts just this week on why long rest (3-5 minutes) between exercise sets is better for optimizing muscle growth compared to 1 minute of rest. This means that these papers are not interpreted in the context of what normal changes look like and what would normally be seen over an 8-12 week time period. Ultimately, this does not mean that there isn't a dose-response between exercise volume and muscle growth, or that long rest periods between exercise sets doesn't lead to better growth over time compared to short rest periods between sets. However, it does mean that some of the current evidence used to support such claims may not be as compelling as many would think.

Changes in Lean Body Mass

Changes in muscle thickness are informative in providing a discussion on the limits of human skeletal muscle growth and adaptation. However, if you have attempted to track your muscle tissue, it seems more likely that you have utilized tools such as “in-body” assessments or other bioelectrical impedance technologies that are able to track changes in lean body mass over time. In addition, some may have access to dual X-ray absorptiometry (DEXA) which is able to provide measurements of bone mineral content, fat-free soft tissue and fat mass. It is important to note that such devices are able to identify tissue as “fat free mass” and may not necessarily reflect local muscle growth accurately. For example, Hoffman et al. [21] examined changes in lean body mass (via DEXA) and muscle thickness (via B-mode ultrasound) of the vastus lateralis following an 8-week split training routine in resistance trained men. The broader purpose of their training intervention was to examine the effects of resistance training alone or resistance training in combination with phosphatidic acid supplementation. However, we can use their findings to learn more about changes in lean body mass, alongside changes in muscle thickness as indicators as the effectiveness of a training intervention. In addition to the supplement, both the supplement group and the placebo group received a standardized 36g amino acid and collagen protein blend post workout. Participants were also asked to complete a dietary recall. The training program is provided in table 2.2. The authors found that following the 8-weeks of training the supplement group increased lean body mass by 2.6%; whereas the placebo condition increased lean body mass by 0.1%. Although there is no statistical difference between these conditions, such a finding may lead you to conclude that the exercise program was rather ineffective for stimulating muscle growth. However, when you look at the muscle thickness data, the supplement and placebo conditions increased by 0.31 and 0.3 cm respectively. These changes in muscle thickness are in line with (and perhaps on the high end) for muscle growth over time. This may demonstrate that direct measures of muscle size are necessary to better capture adaptations to training over time. A reliance on lean body mass relative to direct imaging for muscle growth may take longer to reflect the effectiveness of a training intervention. Thus, if you are tracking your personal progress, don't get too caught up on short term changes in lean body mass as an indicator of muscle growth.

TABLE 2.2 Training program from Hoffman et al. [21]

Monday/Thursday		**Tuesday/Friday**	
Exercise	*Sets/Reps*	*Exercise*	*Sets/Reps*
Bench press*	1,4 x 10-12	Squats*	1,4 x 10-12
Incline DB press	3 x 10-12	Lounge/front squat	3 x 10-12
Seated shoulder press*	1,4 x 10-12	Leg curl	3 x 10-12
Upright rows	3 x 10-12	Knee extension	3 x 10-12
Lateral raises	3 x 10-12	Calf raises	3 x 10-12
Shrugs	3 x 10-12	Lat pulldown	4 x 10-12
Triceps pushdown	3 x 10-12	Seated row	4 x 10-12
Triceps extension	3 x 10-12	EZ bar curl	3 x 10-12
Situps	3 x 25	Dumbbell curls	3 x 10-12
		Situps	3 x 25

Adapted from table 2 Hoffman et al. [21] *All exercises were performed at 70%1RM. They were asked to use a load that allowed 10-12RM.*

A 2019 study [22] examined changes in lean body mass following 8-weeks of either strength type resistance training or endurance type resistance training in resistance trained individuals. For this study, authors considered "strength type" resistance training as a program where individuals performed sets of 6-8RM with 3 min rest between sets; whereas the "endurance type" training program performed sets of 20-25RM with 1 minute rest between sets [22]. Based on what was learned in chapter 1, we would expect that both of these exercise protocols would induce skeletal muscle growth. Both groups trained 4x/week with 2 days allocated to the upper body and the other 2 days allocated to the lower body. The training intervention is provided in Table 2.3. In addition to training, a sports nutritionist made sure that participants consumed a protein intake of 2g/kg/day. They also had to meet a total caloric intake of at least 39 kcal/kg/day. Following the intervention, the strength type training program demonstrated a 1.3kg increase in lean body mass and the endurance type training condition demonstrated no change in lean body mass. However, if the authors had included a measure of muscle thickness, it may be more likely (although not guaranteed) that muscle growth would have occurred in the higher repetition training condition as well. Thus, similar to the previous study [21] it is possible that the changes in lean body mass don't reflect the effectiveness of an exercise intervention given the small magnitude of muscle growth that occurs over such time periods.

Table 2.3 -Training program from Vargas et al. [22]

Group	Exercise Program	Sets	Reps	Rest	Muscle Failure
Strength	Push Pull Program: bench press, pull-ups, dumbbell lateral raise, incline press, barbell row, military press, biceps curl and triceps dip; and (ii) lower limbs: squat, deadlift, leg press, lying leg curl, leg extension, hip thrust, standing calf raise and calf raise press	3	6-8RM	3 min	Yes
Endurance	Muscle groups trained in series: (i) upper limbs: bench press, incline press, military press, triceps dip, pull-ups, barbell row, biceps curl and dumbbell lateral raise; and (ii) lower limbs: squat, leg press, leg extension, deadlift, lying leg curl, hip thrust, standing calf raise, and calf raise press.	3	20-25RM	1 Min	Yes

Regarding changes in lean body mass, it appears that modest changes can be expected over time. For example, Chilibeck et al. [23] examined changes in lean body mass following 20 weeks of full body resistance exercise in a group of non-resistance trained women. Lean body mass was measured using DEXA. The exercise program included several upper body (bench press, lat pulldown, arm curl, and triceps extension) and several lower body exercises (leg press, knee extension, and knee flexion). Participants performed 5 sets of 6-12RM for each exercise. Nutrition was tracked, however there was no nutritional intervention or nutritional requirements prescribed for this study. Following the intervention, authors observed a 1.5 kg (3.7%) increase in lean body mass. Together with the results from Vargas et al. [22], this may suggest that an individual might expect to see a 1-2 kg change in lean body mass over an 8-20 week time period. However the magnitude of change will likely rely on a number of different factors, in addition to the specific training intervention.

Summary on Expectations of Muscle Growth Over Time

The scientific literature provides us important information that helps inform our expectations for muscle growth over time. It seems that in both the upper and lower body, a muscle can increase somewhere in the magnitude of 0.1-0.3 cm over an 8-12 week time period. Also, it is interesting to note that the muscle sizes between individuals in the resistance trained studies and the non-resistance trained interventions are not all that different. For example, the baseline muscle size in the quadriceps in both trained and untrained individuals tends to be somewhere close to 5 cm in both males and females.

So what does this mean? This seems to provide some indication that muscle growth is limited since trained individuals don't appear to have 8 cm thick quads. Muscle growth certainly occurs, but it seems unlikely that a muscle can increase more than 1 cm to 1.5 cm in thickness over a training career. There are likely outliers who can achieve much greater changes in their muscle size with focused training and proper diet. However, much of this will be dictated by their individual genetics. Changes in lean body mass also appear to increase with training. However, within the context of research, it seems to provide us with less useful information on muscle growth (at least in the short-term).

Finally, it seems that muscle growth in some studies is extraordinarily impressive. This makes it difficult to know how to interpret such studies. However, replicating the findings from other research teams would seem to be a great starting point. In future, longer training interventions are necessary to better understand the limits of human skeletal muscle growth.

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06

Exercise volume and muscle growth

Introduction

Within the resistance training literature, it is common to hear the suggestion that volume is the primary driver of skeletal muscle growth. For someone who resistance trains, what does this mean? How many sets of exercise should you be performing? How predictive of muscle growth is the volume of work you perform? There have been several studies conducted which have attempted to answer this important question. However, the science community has been unable to accurately answer the question of how much exercise volume is necessary to maximize muscle growth?. If we look at the meta-analyses carried out on this topic, which is the examination of data from a number of independent randomized control studies on the same subject, the current research concludes that there exists a dose-response relationship between exercise volume and hypertrophy [18]. However, when you pick apart the individual studies included in this meta-analysis, it becomes more difficult to arrive upon this conclusion. This chapter will explore the scientific evidence examining the relationship between resistance exercise volume and muscle growth. In addition, this chapter will seek to summarize the current state of the literature examining volume and growth in order to provide some practical take-aways.

I would be stating the obvious if I said that exercise volume is an important factor in the facilitation of skeletal muscle growth. For example, doing single heavy repetitions will lead to an increase in strength, but will not result in large (if any) changes in muscle size [1,2]. However, if a relatively heavy weight is lifted enough times for enough sets (i.e., volume), skeletal muscle growth tends to be the end result. It is most common to suggest repetition ranges between 8 and 12 in order to facilitate skeletal muscle growth. However, it has also been demonstrated that lighter weights with more repetitions (i.e., 20+ repetitions) will also result in similar skeletal growth (despite the overall lighter training load). Regardless of how heavy or light the weight is (defined as the exercise load), within research, volume is most commonly quantified as the number of sets x reps x load for a given exercise. For example, you could perform 3 sets of 12 RM on the squat exercise, or you could perform 6 sets of 12 RM on the squat exercise on a given training day. Is there a muscle growth benefit to increasing from 3 sets to 6 sets on the squat? Would it be more ideal to do 4 sets? Or, would

1 set of squats be all that is necessary to maximize the growth potential of that training session? The subsequent sections will briefly dive into key scientific papers which have informed this discussion.

Immediate Response to a Single Set or Multiple Set Protocol

When you resistance train you activate a process known as "myofibrillar protein synthesis" (MPS). MPS, as its name implies, suggests you are synthesizing (or making) new myofibrillar proteins (proteins that make up skeletal muscle). Since muscles are composed of myofibers (made up of various myofibrillar proteins, for review see chapter 1), these new proteins will become incorporated into the existing muscle, making that muscle bigger. Interestingly, MPS can be measured through techniques that will trace a protein's incorporation into muscle tissue. Scientists will also look at the activation of various proteins that indicate that you have activated protein synthesis. When MPS is examined, it provides insight into the muscle growth potential of a given training protocol. For example, a training protocol that stimulates MPS would also be expected to facilitate muscle growth when repeated several times over an 8-12 week period.

A 2010 paper by Burd et al. [3] examined the MPS in the vastus lateralis (one of the muscles that makes up the quadriceps) following either 1 set or

3 sets of unilateral knee extension. Authors took baseline muscle samples to examine MPS. Following this, participants performed a fatiguing bout of resistance exercise with an exercise load that corresponded to 70% of their 1RM (a relatively heavy weight). Participants were randomized to perform either a single set or 3 sets of unilateral knee extension with that training load. All exercise sets were taken to the point of failure. For the 3 set condition, 2 minutes of rest was allowed between sets. After the exercise was completed, participants consumed 20g of whey protein isolate. Muscle tissue samples were then taken at 5 hours, 24 hours and 29 hours post exercise. Authors found that MPS was increased in both conditions 5 hours following exercise (2.3 fold for the 1 set group and 3.1 fold for the 3 sets conditions), with the increase in MPS being significantly greater in the 3 set condition. MPS had returned to a value near to baseline in the 1 set condition 29 h post-exercise, while it remained elevated by 2.3-fold in the 3 set condition. These data suggest that we may be stimulating a greater amount of protein synthesis following 3 sets of knee extension compared to one single set. Is this surprising? Not really, most people would expect that it takes more than a single set to maximize the anabolic potential of a training intervention. Overall, the findings of Burd et al. [3] are not controversial. In general, most people would tend to agree that 3 sets of exercise are superior to one single exercise set. However, what happens as we add additional sets? Is 4 sets better than 3 sets? How about 6 sets…Or, even 7 or 8 sets? If a little yields better results, how high can we increase the number of sets by, and still hope to achieve superior gains in muscle growth?

There are several studies that have looked at this. Although there is no specific consensus on how many sets is ideal, we can gather a few practical training recommendations from the data that does currently exist.

A highly cited meta-analysis makes the suggestion that there is a dose-response relationship between exercise volume and hypertrophy [4]. A follow up paper by the same research team, boldly titled: “The dose–response relationship between resistance training volume and muscle hypertrophy: are there really still any doubts?”[5]. One would assume from the name of this title, that the authors no longer feel the need for further discussion or debate concerning the role that exercise volume plays on resistance training induced increases in muscle size. In that same paper, the authors conclude that a minimum of 10+ sets per muscle group per week is necessary to maximize muscle growth, and further note that this recommendation represents a minimum threshold of volume, as there are not enough studies that investigated higher volumes [5]. Despite these bold statements and what appears to be a high volume bias, it is important to point out that the research on this topic is simply not that clear. For example, you can find a number of studies demonstrating a plateau in muscle growth despite increased exercise volume [6-8] while others show that increased training volume leads to greater magnitudes of growth [9,10]. Given such discrepancies in the data, the rest of this chapter will review various research studies on the topic. Such an approach will help you to evaluate the importance of volume and draw your own conclusions (and don’t worry, I will provide my own conclusions on this subject at the end!)

Exercise Volume and Muscle Growth Research Review

In the following pages of research, I will review 5 studies that examine the influence of exercise volume on muscle growth adaptations following resistance training. The review of these studies will not be overly-in depth, but will provide you with a basic understanding of what methods were employed, who was studied (for example, were the participants accustomed to lifting weights or new to resistance training?), and what the authors found. I will conclude each study with a summary statement. At the end of this review section, I will provide my interpretation and practical take away points on exercise volume.

Study 1:

Bottaro, M., Veloso, J., Wagner, D., & Gentil, P. (2011). Resistance training for strength and muscle thickness: Effect of number of sets and muscle group trained. Science & Sports, 26(5), 259-264.

Bottaro et al. [6] examined muscle size and strength adaptations following 12 weeks of resistance training. 24 male participants who were not currently engaged in resistance training were assigned to one of 2 potential training conditions: 3 sets of knee extension and 1 set of bicep curls 1 sets of knee extension and 3 sets of biceps curls.

Participants performed 8-12 repetitions to failure for each exercise set. Participants were instructed to maintain their normal diet for the duration of the study. Muscle size of the biceps and rectus femoris were measured before and after the training program using b-mode ultrasound (note: one of the most reliable tools used in research for measuring muscle growth). Strength was also measured in both muscle groups. Following the intervention, biceps muscle size increased by 7.2% and 5.9% for the 1 set and 3 sets biceps curl groups respectively. There were no significant differences in these changes. When looking at the lower body, changes of 2.5 and -2.9% were observed for the 3 set and 1 set groups respectively. Neither of these changes were statistically significant over time. Strength increased in both groups for the biceps. However, strength only increased in the 3 set condition for the knee extension exercise. Overall, this study demonstrated that muscle growth was not different in the biceps following 12 weeks of performing either 1 set or 3 sets. Interestingly, in the lower body neither 1 set or 3 sets appeared to lead to meaningful growth over time. Thus, for individuals naïve to lifting weights, volume may not be of high importance in the upper body. The lower body data is more difficult to discern, however it may suggest that overall, a greater amount of time is necessary to observe muscle growth in the lower body. Alternatively, the lack of muscle growth may indicate that the training protocol was ineffective, or that some other factor was confounding the results.

Overall, this first study [6] reviewed was unable to detect differences in muscle growth between their 1 set and 3 sets conditions. Some criticisms leveraged against this study may be the training status (maybe exercise volume is less important for those new to training). In addition, the sample size was on the smaller side (a total of 24 individuals in this study).

Study 1 Conclusion:

3 sets was not better than 1 set for upper or lower body muscle growth in untrained individuals.

Study 2:

Ostrowski, K. J., Wilson, G. J., Weatherby, R., Murphy, P. W., & Lyttle, A. D. (1997). The effect of weight training volume on hormonal output and muscular size and function. The Journal of Strength & Conditioning Research, 11(3), 148-154.

Ostrowski et al. [7] examined the effects of different volumes of resistance training on muscle growth adaptations in 27 resistance trained men over a 10-week period. Participants performed either 3 sets per muscle group per week, 6 sets per muscle group per week or 12 sets per muscle group per week. Participants trained 4 times per week. For each of the exercises included in the program, participants completed 12 reps per set for the first 4 weeks, 7 reps per set weeks 5-7 and 9 reps per set for the final 3 weeks. All sets were taken to the point of failure. The exercise performed on each training day are provided in the Table 6.1 below:

Table 6.1 - Exercises performed in Ostrowski et al. [7]

Day 1	Day 2	Day 3	Day 4
Squat	Bench press	Lat pulldown	Barbell curl
Leg Press	Incline bench press	T-bar pulldown	Preacher curl
Leg Extension	Decline bench press	Seated row	Dumbbell curl
Stiff-leg deadlift	Shoulder press	Calf raise	Close grip bench
Leg Curl	Upright row	Calf press	Triceps pushdown
Single-leg curl	Lateral raise	Seated calf raise	Triceps extension

Muscle size of the rectus femoris, (the most superficial muscle of the quadricep), and the triceps brachia were measured pre and post intervention using ultrasound technology. Authors made no mention of the participants diet or nutritional habits. Following the training intervention, authors found that the triceps brachia increased by 2.3%, 4.7% and 4.8% in the low, moderate and high volume groups respectively. There were no statistical differences between the different training conditions. For the rectus femoris, muscle cross-sectional area increased by 6%, 5% and 13% in the low, moderate and high volume groups respectively. Similar to the triceps, there were no statistical differences between the different training conditions. Authors concluded that higher volume protocols showed no significant differences in their training effects over the 10-week period. They further speculated that once a minimum threshold of volume is reached, further increases in volume are no longer advantageous. This study would suggest that if you are a trained individual, there may be little benefit to an exercise program with higher volume compared to a program utilizing a relatively lower volume. However, it may be fair to criticize the sample size in this study (only 9 people per group). Perhaps with a larger sample size, the authors would have been able to detect significant differences? Or maybe this highlights that high volumes aren't necessary for long term muscle growth adaptations.

Study 2 conclusion:

Over a 10 week training period, in previously resistance trained individuals, there were no differences in upper or lower body growth between full body training programs that utilized either 3, 6 or 12 sets of exercise per muscle group per week.

Study 3:

Heaselgrave, S. R., Blacker, J., Smeuninx, B., McKendry, J., & Breen, L. (2019). Dose-response relationship of weekly resistance-training volume and frequency on muscular adaptations in trained men. International Journal of Sports Physiology and Performance, 14(3), 360-368.

Heaselgrave et al. [8] examined muscle size adaptations following 6 weeks of resistance training at either low (9 sets per week), moderate (18 sets per week), or high (27 sets per week) training volumes in 49 resistance trained males. The training program is provided in Table 6.2 below. Participants in both groups performed three exercises per training visit (seated supine biceps curl, supine grip bent-over row, supine grip pulldown). The low volume group only trained once per week, whereas the other 2 groups trained twice per week. Muscle thickness of the upper arm (biceps) was measured pre and post intervention using ultrasound technology. Participants were instructed to maintain their normal diet and supplement intake.

Table 6.2 - Training program from Heaselgrave et al. [8]

	Day 1	Day 2
Low volume	3 sets of seated supine biceps curl	**NA**
	3 sets of supine grip bent-over row	
	3 sets of supine grip pulldown	
Moderate volume	3 sets of seated supine biceps curl	3 sets of seated supine biceps curl
	3 sets of supine grip bent-over row	3 sets of supine grip bent-over row
	3 sets of supine grip pulldown	3 sets of supine grip pulldown
High Volume	5 sets of seated supine biceps curl	4 sets of seated supine biceps curl
	5 sets of supine grip bent-over row	4 sets of supine grip bent-over row
	4 sets of supine grip pulldown	5 sets of supine grip pulldown

Training program for low, moderate and high volume training groups. Participants performed 10-12 reps per set, with 2 reps in reserve at the completion of each set.

Following the training intervention, authors observed that there was no between-group difference in the relative or absolute change in muscle size following the training program. Changes of 0.1 cm, 0.3 cm and 0.2 cm were observed for the low, moderate and high volume conditions respectively.

The results of this study would suggest that, in resistance trained individuals, short term (6-week) changes in biceps muscle size are similar between low, moderate and higher training volumes. The magnitude of changes observed is in line with what one might expect to see over this time period. It may be argued that a limitation of this study is the short-term nature. Being that it was only 6 weeks, it is possible that different volumes would result in varying levels of growth over longer time-frames? However, it is worth noting that the sample size in this study was marginally better than other studies examining volume and muscle growth (49 total in the study and 15-17 individuals per group, which is the highest in the studies included in this review).

Study 3 conclusion:

Results of Heaselgrave et al. [26] suggests that low, moderate and high training volumes result in similar biceps growth over a 6 week time period in resistance trained individuals.

Study 4:

Schoenfeld, B. J., Contreras, B., Krieger, J., Grgic, J., Delcastillo, K., Belliard, R., & Alto, A. (2019). Resistance training volume enhances muscle hypertrophy but not strength in trained men. Medicine and science in sports and exercise, 51(1), 94.

Despite some studies finding no inherent benefit to higher resistance training volumes, other studies have found a very clear dose-response relationship with exercise volume and muscular adaptation. For example, Schoenfeld et al. [9] observed muscle growth adaptations in 34 resistance trained males performing either 1 set, 3 sets or 5 sets per exercise (per session) over an 8-week period. Participants were instructed to maintain their normal diet. In addition, participants were provided a protein shake (24g protein, 1g carbs) on training days. The training program was a full body program consisting on the following 7 exercises: Flat barbell bench press, barbell military press, wide grip lateral pull down, seated cable row, barbell back squat, machine leg press, unilateral machine leg extension.

This study was unique in that it included exercises that might (to some level) represent what an individual would actually perform in their resistance training program. Now remember, some individuals in this study are performing 1 set for each exercise and some are performing either 3 or 5 sets per exercise. Individuals performed 3 training sessions per week and performed 8-12 repetitions to the point of failure for each exercise set. Muscle size in the upper and lower body was measured pre and post intervention using ultrasound technology.

When looking at the study results, there appeared to be a dose-response relationship between exercise volume and muscle growth that was observed in both the upper and lower body. To provide an example, for the biceps muscle thickness, the change in muscle size for the 1 set group over 8 weeks was 0.7 mm. In comparison, changes of 2.1 mm and 2.7 mm were observed for the 3 sets and 5 sets groups respectively. For the triceps muscle thickness, there was no difference between conditions. Looking at the rectus femoris (front of the thigh) the 5 set condition appeared to experience more growth compared to the 1 set or 3 sets groups (see table 3.3 below for values). There was not strong evidence that the 3 set condition grew more than the one set condition. For the vastus lateralis (outer thigh), 3 sets was better than 1 set and 5 sets was better than 3 sets (see table 6.3 below for muscle thickness values). All changes in muscle size, as well as pre and post muscle thickness values are provided in table 6.3 below:

Table 6.3 - Training program from Schoenfeld et al. [9]

Muscle Site	Sets per exercise	Pre muscle thickness	Post muscle thickness	Change in muscle thickness
Biceps Thickness millimeters	1 set	42.6 ± 4.3	43.3 ± 5.1	0.7 ± 2
	3 sets	44.6 ± 5.9	46.7 ± 5.8	2.1 ± 1.6
	5 sets	41.9 ± 3.6	44.8 ± 4.1	2.9 ± 1.7
Triceps Thickness millimeters	1 set	47.2 ± 4.5	47.7 ± 4.6	0.6 ± 2.0
	3 sets	48.4 ± 6.2	49.8 ± 6.3	1.4 ± 3.1
	5 sets	47.1 ± 3.5	49.7 ± 4.9	2.6 ± 2.3
Rectus femoris thickness millimeters	1 set	59.7 ± 6.7	61.7 ± 5.5	2.0 ± 2.6
	3 sets	57.9 ± 8.1	61.0 ± 8.7	3.0 ± 3.1
	5 sets	54.4 ± 3.4	61.2 ± 4.5	6.8 ± 3.6
Vastus lateralis thickness millimeters	1 set	57.5 ± 6	60.4 ± 6.3	2.9 ± 1.9
	3 sets	57.9 ± 8	62.5 ± 7	4.6 ± 2.3
	5 sets	52.4 ± 6.2	59.6 ± 5.8	7.2 ± 3

Muscle data adapted from table 1 Schoenfeld et al. [27]. Table 6.3 displays pre and post muscle thickness values reported in millimeters. The far right column displays the average change score. All data are means ± SD.

Based on their findings, authors concluded that muscle hypertrophy follows a dose-response pattern with “increasingly greater gains achieved with higher training volumes” [9]. These findings are in somewhat contrast to the previously reviewed paper by Bottaro et al. [6], with perhaps the key difference being training status of the individuals enrolled in the study. For example, the individuals in the Schoenfeld investigation were "resistance trained" whereas the individuals in the Bottaro paper [6] were not resistance trained. Interestingly, it has been pointed out that non-resistance trained individuals typically grow at much larger magnitudes compared to trained individuals. This is because trained individuals tend to be closer to maximizing their growth potential. In taking a closer look at the paper by Schoenfeld and colleagues [9], it is also noteworthy that the magnitudes of muscle growth are quite high, and outside of what is typically seen given the short amount of time. For example, a comparable study by Jakabowski et al. [11] examined changes in muscle thickness of the vastus lateralis (same muscle group imaged by Schoenfeld et al.), also carried out in resistance trained men following 12 weeks of full body resistance training combined with either whey + leucine supplementation or whey + hmb supplementation. Interestingly, the authors observed no difference between their respective conditions, with changes of 0.1 cm and 0.2 cm in the leucine and hmb conditions respectively. The changes observed by Schoenfeld over 8 weeks were of a much higher magnitude (3x the growth in fact), compared to what was observed in this study. This doesn't mean that there is not a dose response relationship between volume and growth, but when we compare these two studies, what it does indicate is that the data available may not be as compelling as many might suggest. Given the extraordinary magnitude of growth observed by Schoenfeld et al. [9] it seems possible that muscle damage (maybe this caused swelling?) in response to the high volumes of exercise may have confounded the results. In addition, this study (similar to the previous studies) had a relatively small sample size with 11-12 individuals per group, which may limit our ability to draw strong conclusions.

Study 4 conclusion:

Authors of the Schoenfeld et al. study concluded that there was a general dose-response between the number of sets performed within a training session and the muscle growth observed over time in a group of resistance trained men.

Study 5:

Radaelli, R., Fleck, S. J., Leite, T., Leite, R. D., Pinto, R. S., Fernandes, L., & Simão, R. (2015). Dose-response of 1, 3, and 5 sets of resistance exercise on strength, local muscular endurance, and hypertrophy. The Journal of Strength & Conditioning Research, 29(5), 1349-1358.

Radaelli et al. [10] examined muscle growth adaptations following 6 months of full body training (exercises provided below) in 48 Brazilian Navy School of Lieutenants who had no experience lifting weights (they were experienced with bodyweight exercises such as push-ups, pull-ups and abdominal exercises). Participants completed three sessions per week. Individuals were randomized into groups performing either 1 set, 3 sets or 5 sets per exercise. All training groups performed 8-12 repetitions to failure for each set, with 90-120s rest between exercise sets. Participants were instructed not to change their diet over the course of the study. The exercises completed are listed below: Bench press, leg press, front lat pulldown , leg extension, shoulder press, leg curl, biceps curl, abdominal crunch lying on the floor, triceps extension.

Muscle size of the elbow flexors (biceps) and elbow extensors (triceps) was assessed pre and post intervention using ultrasound technology. Following the intervention, the authors observed a dose-response pattern in the biceps, with 3 sets being better than 1 set, and 5 sets being better than 3 sets. For the triceps, growth was only observed in the 5 sets condition. The absolute changes in muscle size are harder to discern in this study, given that the data is provided in figure form. However, using an online graph reader (http://www.graphreader.com), it was determined that the elbow flexors increased from 3.5 cm to 3.8 cm in the 3 set condition (a mean change of 0.3 cm) and increased from 3.5 cm to 4.1 cm in the 5 set condition (a mean change of 0.6 cm). For the elbow extensors, muscle thickness increased from 3.9 cm to 4.0 cm (a mean change of 0.1 cm) and from 3.8 to 4.8 (a mean change of 0.9 cm) for the 3 set and 5 set conditions respectively. These results would be in agreement with Schoenfeld et al. [9]. The authors of the current study concluded that there appears to be a dose response between volume and muscle growth in the upper body. First and foremost, it is highly commendable that these authors were able to conduct a 6 month study, as it is extremely difficult to conduct training interventions that are this long in duration in the research field. A possible limitation of this study however, is that there are relatively small sample sizes within each training condition (12-13 individuals per group). In addition, the changes observed in their high volume condition are extremely high. It is possible that the longer duration (6 months) allowed a greater amount of muscle growth than what is typically observed. However, even with this taken into consideration, the difference from performing 3 sets of exercise versus 5 sets of exercise seems drastically different (for example, 0.1 cm growth vs. 0.9 cm growth would suggest 9x the magnitude of muscle growth for 5 sets vs. 3 sets). If 5 sets is better than 3 sets, it is unlikely that the observed differences in growth are as drastic as what was observed in this study. Thus future replication of this finding is necessary.

Study 5 Conclusions:

In non-resistance trained men, there appeared to be a dose-response relationship between training volume (1, 3 or 5 set/s per exercise per session) and muscle growth in the biceps. High volume (5 sets per exercise appeared to be the only protocol that induced triceps growth over the time period.

Summary and Conclusions on Exercise Volume and Muscle Growth

The current state of the literature makes it difficult to draw clear conclusions on the importance of exercise volume beyond 3 sets per exercise. Although meta-analyses [4] on the topic have come to the conclusion that there exists a dose-response relationship between volume and growth over time, it may not be appropriate to run such analysis when labs have such different findings (i.e., the magnitudes of growth observed are not comparable). For example, one of the most cited papers [9] concluding that there exists a dose response in exercise volume and growth, found increases in lower body muscle thickness that are of a magnitude that is 3x what other research labs are finding over the same period of time [11]. Thus, there may have been confounding factors in some of the studies, or labs may be using different techniques (even when using similar muscle imaging devices). Overall, growth seems to occur across a wide range of exercise volumes. There is evidence to suggest that there may be little difference between 3 sets of exercise and 5 sets of exercise per training session. Many research labs appear to split the difference and have individuals perform 4 sets to failure as a common hypertrophy stimulus [2]. For example, a paper by Buckner et al. [2] utilized 4 sets to failure as a hypertrophy stimulus while 2 sets to failure are used as a muscle growth maintenance stimulus. Overall, I would encourage the reader to consider that, despite the common narrative in the fitness industry, there is still no clear indication that there is an endless dose-response relationship between hypertrophy and exercise volume. I would go as far as to saying that muscle hypertrophy appears to be maximized somewhere around 3-4 working exercise sets when performed to (or near) failure for a given exercise. Future studies with larger sample sizes, longer study durations (6 months -1 year), which also consider the potential for inflammation and swelling due to muscular damage as a confounding error in response to higher training volumes, are necessary to answer this question once and for all.

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