Regional hypertrophy: the role of exercise resistance profile in trained women

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Abstract

Purpose

The aim of the present study was to analyse the role of exercises' resistance profile in regional hypertrophy.

Methods

39 healthy women completed a 9-week resistance training program consisting of either 4 sets of 12 repetitions of inclined bicep curls (INC group) or preacher curls (PREA group) three times per week to muscle failure. Pre- and post-intervention muscle thickness was measured using B-mode ultrasound imaging with a linear-array transducer. Scan acquisition sites were determined by measuring the 50%, 60% and 70% of the distance between the posterior crest of acromion and the olecranon.

Results

No region of the INC group grew when comparing pre- to post-intervention. The 70% region of the PREA-group grew (Muscle thickness increased from 2.7 ± 0.43 to 2.94 ± 0.44). We found no growth differences between regions when analysing per group ($p = 0.274$), region ($p = 0.571$) or group*region ($p = 0.367$).

Conclusion

This study shows that regional hypertrophy is affected by the resistance profile of an exercise. Different regions of a muscle will grow in response to exercises that place the highest difficulty in specific points of the range of motion. Our results show that the distal region of the arm grows in response to exercises that place the highest amount of strain in the part of the range of motion in which the arm muscles are more elongated.

Introduction

Muscle growth, also known as muscle hypertrophy, is a complex process highly dependent on mechanical force (Wackerhage 2019, Schoenfeld 2021). This physiological event is related to performance improvements in many sports (Storey and Smith 2012) and implies a lower mortality risk in different populations (Wannamethee et al. 2007; Srikanthan and Karlamangla 2014; Srikanthan et al. 2016; Sedlmeier et al. 2021).

Muscle does not grow homogeneously (Zabaleta-Korta et al. 2020) as it can differ between the heads of a muscle and even between the different regions of a single head (Zabaleta-Korta et al. 2020). This phenomenon, known as regional hypertrophy, has drawn a considerable amount of attention in recent years (Diniz et al. 2020; Martins-Costa et al. 2021; Zabaleta-Korta et al. 2021). Several factors seem to influence regional hypertrophy, including exercise selection (Diniz et al. 2020; Martins-Costa et al. 2021; Zabaleta-Korta et al. 2021), time under tension (Martins-Costa et al. 2021), time spent in each phase of an exercise (Diniz et al. 2020) or even performing only concentric/eccentric exercises (Franchi et al. 2014, 2018b). In all of them, applied muscle force appears to be an important factor that somehow shapes which region of muscle will grow (Zabaleta-Korta et al. 2021).

Recently, Zabaleta-Korta et al. (2021) found that exercise selection may elicit differing regional hypertrophy stimulus. However, since the exercises studied placed strain in different parts of the range of motion (RoM), it was not possible to know whether the regional hypertrophy reported was due to exercise selection or to resistance differences that the involved joints had to overcome. It is known that the region of the RoM in which the highest strain is placed, is the one in which athletes become strongest (Staniszewski et al. 2017; Valamatos et al. 2018). Since studies analyzing this effect did not measure muscle growth, we cannot conclude that strength increases were not produced by regional hypertrophy nor that non-homogenous muscle growth acts in parallel to strength gains.

Comparisons between exercises with different resistance profile, defined as the degree of resistance in each part of the RoM of a joint, have been reported previously (Staniszewski et al. 2020), although with the aim of analyzing general muscle growth, and not regional hypertrophy. Thus, the aim of the present study was to analyze the role of exercises with different resistance profiles in regional hypertrophy. To that purpose, inclined bicep curl and preacher bicep curl exercises were compared in three different regions of the arm. The first exercise places the highest amount of strain at the end of the exercise, when the arm muscles are totally flexed, while the latest places the highest amount of strain at the beginning, with a considerable amount of elongation in the biceps brachii and brachialis muscles. In addition, we decided to perform the study in women, as most regional hypertrophy studies analyze this phenomenon in men.

Methods

Experimental approach to the problem

Two exercises with different resistance profiles were chosen for the present study: inclined bicep curls and preacher curls. The first one places the highest amount of difficulty at the end of the exercise, with the elbow in a 90º position. The resistance increases along the RoM of the exercise, that is, an ascending kind of resistance (Figure 1). The second one places the highest amount of difficulty at the beginning of the exercise, with the elbow in a 180º position (Figure 1). The resistance decreases along the RoM of the exercise, that is, a descending kind of resistance. To avoid the influence that the resistance of other exercises may have in the adaptations to the exercises included in the study, participants were not allowed to perform any other biceps brachii or pulling exercises during the intervention.

To assess muscle growth, muscle thickness (MT) measurements were performed. MT was chosen instead of cross sectional area (ACSA) as performing reliable ACSA measurements with an ultrasound apparatus is difficult and operator dependant (Hernández-Belmonte et al. 2022). MT is defined as the thickness of all the muscles in the arm (biceps brachii and brachialis) in the field-of-view of the probe, from the skin interface to the humerus. Each region's growth was analyzed individually and compared to the growth of other regions. The intervention lasted 9 weeks.

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Subjects

39 healthy women joined this study. Participants were required to meet the following inclusion criteria 1) Women with an age ranging between 18 and 45 years; 2) lack of musculoskeletal disorders in the upper limbs at least one year prior to the beginning of the study and 3) A resistance training experience of at least 6 months prior to the beginning of the study.

A total of 32 participants finished the study. Two participants dropped out because they tested positive for SARS-COVID19 and five participants dropped out for personal reasons not related to the study. Written informed consent was obtained from each participant after a thorough explanation of the testing protocol, the possible risks involved and the right to terminate participation at will. The study was approved by the Institutional Review Board of the University of the Basque Country UPV/EHU (ref. 118/2019) and all procedures were done in accordance with declaration of Helsinki (2013). Participants were analysed by the intention-to-treat principle in order to avoid the risk of bias (McCoy 2017) even if 2 participants did not reach the 90% of attendance to the planned training sessions.

Procedures

Measurements were performed 2 days prior to the beginning of the training program and 72–96 h after the end of it. Measurements lasted ~30 min and testing sessions were carefully scheduled to ensure that the same number of hours were left since the end of the training protocol. During the day of the first measurements, participants were randomly allocated into the INC and PREA groups. Participants in the INC group completed a 9-week resistance training program consisting of 4 sets of 12 repetitions of inclined bicep curls three times per week taking each set to muscular failure. Inclined bicep curls consisted on performing bicep curls with a dumbbell while lying supine in a bench with 45º inclination. Exercise began with the forearm perpendicular to the floor, and ended when the elbow angle was less than 90º. Participants in the PREA group completed the same training protocol, but performed the preacher bicep curl instead of the inclined bicep curl. The preacher bicep curl consisted on performing bicep curls with a dumbbell in a Scott bench. A Scott bench is a special kind of bench consisting on a 50º inclined platform where the participant places the arm while performing de curling movement. The exercise begins with the forearm parallel to the floor or slightly below, and ends when the forearm forms a 75º angle with the floor, never reaching a position perpendicular to the floor. Participants in both groups were requested not to perform any other biceps brachii or pulling exercises (also known as back exercises), that would directly or indirectly affect the stimulus provided by the exercises of the study. To make it easier for the participants to organize their training sessions with the conditions of the study, they were offered different training plans according to the number of days they wanted to train. They were also encouraged not to perform strenuous pulling or bicep-demanding activities during the period of the study.

Weekly training volume consisted of 12 weekly sets (Baz-Valle et al. 2018) for the biceps brachii exercise and varied between 60 and 85 sets for the rest of the muscles (depending on the number of days that each subject trained). This amount of weekly sets follows current guidelines of weekly resistance exercise volume to maximize muscle growth (Baz-Valle et al. 2022).

Training was periodized in a flexible fashion: the first day, participants were told to adjust the weight so that they could reach muscular failure at 12 repetitions. For that purpose, participants were told to choose a weight that would make them reach but not exceed 12 repetitions on their exercise. If they were able to perform 1–3 extra repetitions with the chosen weight, they had to use the next heaviest dumbbell. If the weight difference between dumbbells was too high (in some gyms, the weight difference between one dumbbell and the next heaviest one is 2.5 kg. As most participants lifted 10 kg, that's a 25% increase), participants were given to options: They could lift a heavier weight and perform as many repetitions as possible trying to reach 12, or perform more repetitions than 12, always reaching volitional failure. Participants were suggested to lift a heavier weight if they could perform more than 6 repetitions with it or to choose performing more repetitions if they felt they couldn't, but to never exceed 18 repetitions. We consider that the fact that the subjects weren't performing the same number of repetitions occasionally didn't had any effect on the results, as muscle size improvements are not affected by the number of repetitions performed while the repetition range does not exceed 20 or go under 6 (Baz-Valle et al. 2018; Schoenfeld et al. 2021)

As the duration of each of the phases of an exercise seems to induce regional hypertrophy (Diniz et al. 2020), the eccentric phase of the exercise had to last 2 seconds, and the concentric part of the exercise had to be performed as fast as possible for participants in both groups. Participants were also requested to rest at least 48 h between training sessions. Resting between repetitions was not allowed, and participants had to rest from 3 to 5 min between sets. Training sessions took place at the gyms in which each participant usually trained. To test whether the participants performed the exercises with the correct form, and with the right intensity, each participant had to send a video performing an effective set to the main researcher after every session. Participants registered the weight lifted in each set in a mobile phone APP (Dudysolutions version 2.3, 2020 Spain) so that they could see the weight lifted and the repetitions performed in previous sessions, and try perform better.

Muscle thickness

Muscle size/thickness was measured using B-mode ultrasound imaging (GE LOGIQTM e, GE Healthcare, WI, USA) with a linear-array transducer (code 12 L-RS, variable frequency band 4.2–13.0 Mhz, field of view 3.7 mm). Measurements were performed by an experienced technician with participants in a supine position, with arms and legs extended and relaxed. Prior to testing, participants remained in this position for 10 minutes to allow for stabilization of normal body fluids. The technician then applied a watersoluble transmission gel (Aquasonic 100 Ultrasound Transmission gel; Parker Laboratories Inc., Fairfield, NJ, USA) to each measurement site and a 9 MHz ultrasound probe was placed parallel to the tissue interface without depressing the skin. When the quality of the image was deemed as satisfactory, the technician saved the image to the hard drive. Scan acquisition sites were determined by measuring the 50%, 60% and 70% of the distance between the posterior crest of acromion and the olecranon as performed in previous articles (Matta et al. 2011). When determined, a circle was drown around the circumference of the arm in those three spots. After that, the center of the biceps brachii muscle was calculated as a line between the coracoid process and the anterocubital crest. The scan was taken in the place were both lines crossed. Thickness was measured using the line straight function of ImageJ software (Kim et al. 2020) in the center of the scan (Figure 2). Measurements were taken on the right side of the body.

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Body fat percentage and anthropometric measurements

One day before and 3–4 days after the 9-week intervention, anthropometric characteristics of the participants were measured. Participants were weighed on a calibrated digital scale whilst wearing minimal clothing. Height was measured with a stadiometer attached to the scale with participants standing shoeless and head aligned in the horizontal Frankfurt plane. Eight-site skinfold measurements (in mm) were taken from the biceps brachii, triceps, scapular, abdominal, suprailiac, thigh and medial calf sites according to standard procedures using a skinfold caliper (Harpenden1, Baty International, West Sussex, UK). All skinfolds were measured to the nearest 1 mm and the mean of three readings was recorded as the final value for each site. All body composition measurements were taken by the same investigator 24–48 h before and 72–96 h after completion of the training protocol. Body fat percentage (%BF) was estimated using the equation proposed by Faulkner (Faulkner 1966).

Dietary Adherence

To avoid the potential for dietary confounding, participants were given a document in which they were instructed to reach 2 $g \cdot kg^{-1}$ of protein intake. First, they were taught how to calculate how much protein they needed according to their bodyweight. Then, they were instructed on how to reach that amount with examples of different dishes and were requested to include at least 20 g of protein per meal divided into 3 to 5 meals with at least 3 hours between them. Participants were also trained to be in an eucaloric diet or slight energy surplus. Participants also agreed not to take any supplements that could interfere with the study outcomes (such as creatine or whey protein).

Statistical analyses

We tested all variables for normal distribution (Shapiro-Wilk test) and homogeneity of variances (Levene's test). An independent sample *t* test was used to check for significant differences in MT and %BF variables prior to the beginning of the study. If Levene's test was significant, Welch's correction method was used. Paired sample *t* test were applied to compare the PRE and POST measurements of each region of each group to determine which of regions had grown during the intervention and whether fat percentage had changed or not. Wilcoxon signed rank test was used if the variable did not have a normal distribution. Cohen's *d* was calculated to analyze the magnitude of the potential PRE-POST differences between participants if the variable had a normal distribution. Rank biserial correlation was used for the non-parametric variables. Effect sizes were interpreted as small (<0.3), moderate (≥0.3 and <0.5), and large ≥0.5) according to the scale proposed by Cohen (Cohen, 1988) when the variable was parametric and as and small (<0.1), medium (≥0.3 and <0.5) or large (≥0.5) when the variable was non-parametric. A multifactorial ANCOVA was performed in order to check growth differences between regions (Group x region x time). For the ANCOVAs, effect sizes were calculated as partial η^2. In this case, effect sizes were considered irrelevant (<0.01); small (≥0.1 and <0.6); medium (≥0.6 and <0.14); or large (≥0.14). An intra-class correlation coefficient test was performed to measure the reliability of the measurement protocol, in a pilot study carried out with 10 participants. All the statistical analyses were performed with JASP 0.16 for Mac. The level of significance was set at p<0.05.

Results

We found no differences between groups in the size of the 50% (p=0.613), 60% (p=0.870) and the 70% (p=0.727) regions, nor in the body fat percentage (p=0.18) prior to the beginning of the study.

Growth of regions

No region of the INC group grew during the study (p=0.95 ES=0.019; p=0.520, ES=-0.242 and p=0.536, ES=-0.193 in the 50%, 60% and 70% regions respectively).

The 70% region of the PREA-group grew significantly (p=0.017, ES=-0.623), and we observed a trend towards an increase in the 60% region as well (p=0.071, ES=-0.503). In contrast, we did not find any growth in the 50% region (p=0.347 ES = -0.263).

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Differences in body fat percentage

No differences were found in fat percentage after the intervention within the INC group (p=0.248, ES=0.337) nor within the PREA-group (p=0.188, ES=0.333). Body fat percentage did not differ between groups neither before (p=0.18) nor after (p=0.252) the intervention.

ICCs

Intra-class correlation coefficient for the researcher and the ultrasound apparatus used for the study was ICC = 0.98. Showing a very high degree of agreements between measurements, and demonstrating our protocol to be very highly reliable (Munro 2005).

Discussion

The main finding of this study was that the distal region of the arm grew in response to an exercise with a descending resistance profile, while the rest of the regions of that group and all the regions of the other group did not. This means that the resistance profile of an exercise seems to contribute to the growth of a given region inside the arm muscles, thus affecting regional hypertrophy.

The question arises on how resistance profile differences produce differing adaptations in a given region of a muscle. One option may be the degree of elongation of the muscle during the exercise. Evidence suggests that training at long muscle lengths may increase sarcomere length (Wisdom et al. 2015), which may elicit further increases in muscle size in the distal region. In fact, some muscles seem to benefit from being trained at long muscle lengths when compared to short muscle lengths (Schoenfeld et al. 2021; Kassiano et al. 2022). In this regard, our results are in line with previous studies as Sato et al. (2021) found a greater increase in the MT of the distal region of the arm (70% of the distance between lateral epicondyle and acromion) after performing preacher curl at long muscle lengths *vs*. short muscle lengths. This suggest that when the arm muscles work in long muscle lengths, distal region undergo higher tension than the rest (Nosaka and Sakamoto 2000). In the distal region, the brachialis muscle is more present than in more proximal regions. In fact, in the scans of some participants in the present study, biceps brachii and brachialis muscles could be distinguished to the point that in the 70% region, the brachialis muscle was twice as thick as in the 50% region. Probably, working at long muscle lengths stimulates the brachialis muscle more than the biceps brachii muscle. However, due to the length-tension relationship of the elbow flexors, elbow flexion is not very effective at long muscle lengths (Ismail and Ranatunga 1978). This may have stimulated the brachialis, by far the strongest elbow flexor (Kawakami et al. 1994) to a greater degree than the biceps brachii in the preacher curl exercise. On the other side, the inclined biceps curls, whose major difficulty occurs when the biceps brachii is in a shortened position, were not enough to stimulate any part of the biceps brachii.

The explanation may also lie in the neural strategy used by each participant to face the requirements of the exercise, as previous research has shown that some people have the ability to selectively choose muscles that perform the same exercise (Avrillon et al. 2021). Recent evidence suggests that the moment generated by each joint can be predicted by decoding the neural signal arriving to the muscles (via HD EMG measurements *in vivo*) (Sartori et al. 2017). Future research on regional hypertrophy should focus in understanding the interplay between the mechanical role of a muscle region and the neural signals it receives, as muscle hypertrophy happen as a result of both mechanical forces and neural inputs (Alix-Fages et al. 2022).

Even if the current results are in line with previous research (Sato et al. 2021), other authors have found no differences in regional hypertrophy of the arm muscles after performing preacher curls (Drummond et al. 2016). However, in this study the special equipment used placed the major difficulty when the biceps brachii was in a shortened position, and all the subjects performed preacher curls (not any other exercise, with any special kind of resistance) which shows the importance of mechanical stimuli and resistance profiles for regional hypertrophy (Franchi et al. 2018b). In addition, another study found that after performing eccentric exercises with blood flow restriction, the difference between region growth was greater than when performing concentric biceps curls with blood flow restriction (Yasuda et al. 2015). This data shows once again the influence of contraction type in regional hypertrophy, and outlines the importance of standardizing the time spent performing concentric or eccentric actions during a repetition in regional hypertrophy studies to avoid confusion factors. However, it should be noted that the distal part of the arm is the biggest one (Matta et al. 2011; Sato et al. 2021), and for that reason it is also the one we should expect to grow the most (at least in terms of absolute growth). In fact, growth in the most distal part of the arm can be found in 4 studies (including the present one), while the rest of the regions do not always grow (Matta et al. 2011; Yasuda et al. 2015; Sato et al. 2021). There is one exception though, Drummond and colleagues reported that the medial region was the biggest one (Drummond et al. 2016).

This study faced several limitations. Muscle is a three dimensional organ, and for that reason the optimum quantification of its growth is three-dimensional (Franchi et al. 2018a). We performed ultrasound scans, which only allows to perform MT or ACSA measurements. Since the techniques used to measure ACSA from ultrasound scans are too complex and operator dependant (Hernández-Belmonte et al. 2022) and MT has a very high correlation with ACSA (Franchi et al. 2018a), we deemed it an acceptable way to measure muscle growth. The ICC shows a high degree of agreement between measurements, that can also be seen elsewhere and confirm that measuring MT with ultrasound scans is a reliable manner to quantify muscle growth (Palmer et al. 2015; Franchi et al. 2018a). However, the backside of the ultrasound scans is that we could not distinguish whether the measured growth was due to the biceps brachii or brachialis muscle.

In conclusion, this study shows that regional hypertrophy is affected by the resistance profile of an exercise. This means that different regions of a muscle will grow in response to exercises that place the highest difficulty in specific points of the range of motion. In particular, our results show that the distal region of the arm grows in response to exercises that place the highest amount of strain in the part of the range of motion in which the arm muscles are more elongated.

PRACTICAL APPLICATIONS

According to the results of this study, the resistance profile of any exercise changes the manner in which the involved muscles grow. For example, when aiming to increase the size of the elbow flexors in the part that is closest to the elbow, using exercises in which the highest strain is posed when the muscles are elongated seem to be the best option. This is key in sports such as bodybuilding in which shape, size and symmetry of muscles are evaluated in competition.

According to recent evidence, these findings may also be extrapolated to other muscles such as the quadriceps femoris, and may be one of the factors behind the principle of specificity: the fact that strength is increased in the part of the RoM of a joint in which an athlete trains. This can be applied to sports like swimming, in which high amounts of force are applied when the elbow and shoulder muscles are elongated (i.e. in free-style swimming). Practitioners can thus benefit from performing exercises that pose the major difficulty when these muscles are in this very same position. This would make muscles on the distal part bigger, which may have important functional implications, such as the ability to apply high amounts of force in this region of the RoM, which would ultimately lead to improved performance.

Abbreviations

INC	Inclined Bicep Curl Group
PREA	Preacher Bicep Curl Group
RoM	Range Of Motion
ACSA	Anatomical Cross-Sectional Area
MT	Muscle Thickness
%BF	% Body Fat
ANCOVA	Analysis Of Covariance
ICC	Intraclass Correlation Coefficient
HD EMG	High Density Electromiography

Declarations

COMPETING INTERESTS

Authors declare no conflict of interest.

AUTHOR CONTRIBUTION STATEMENT

AZK, JSC and EFP designed the study, and recruited the participants, while only AZK wrote the first draft. In addition, AZK analyzed data from ultrasound scans to obtain MT. AZ performed the statistical analysis. MF and JTU performed and helped to analyze the ultrasound scans.

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Tables

Table 1. Mean muscle thickness per region (*n*=32)

	50% PRE	60% PRE	70% PRE	50% POST	60% POST	70% POST
INC	2.19 ± 0.28	2.3 ± 0.38	2.74 ± 0.43	2.24 ± 0.32	2.41 ± 0.23	2.81 ± 0.44
PREA	2.13 ± 0.34	2.32 ± 0.43	2.68 ± 0.43	2.27 ± 0.43	2.5 ± 0.38	2.94 ± 0.44*

INC, inclined biceps curls group; PREA, preacher curls group. Values are Means ± SD. *Significantly different from PRE.

Figures

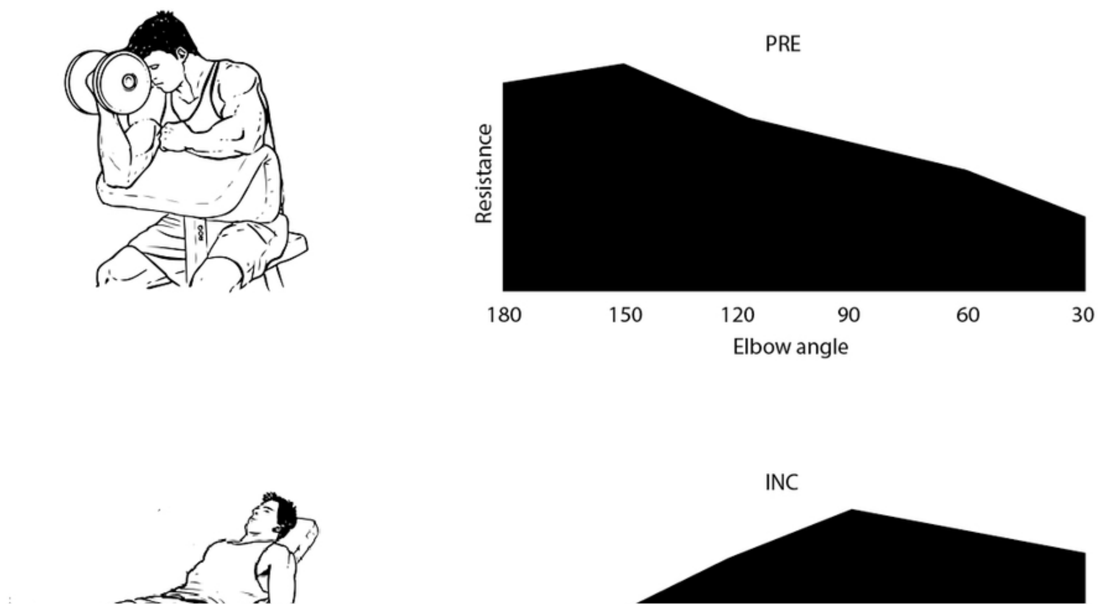

Figure 1

Incline press (INC) and preacher curls (PREA) exercises and their resistance profiles

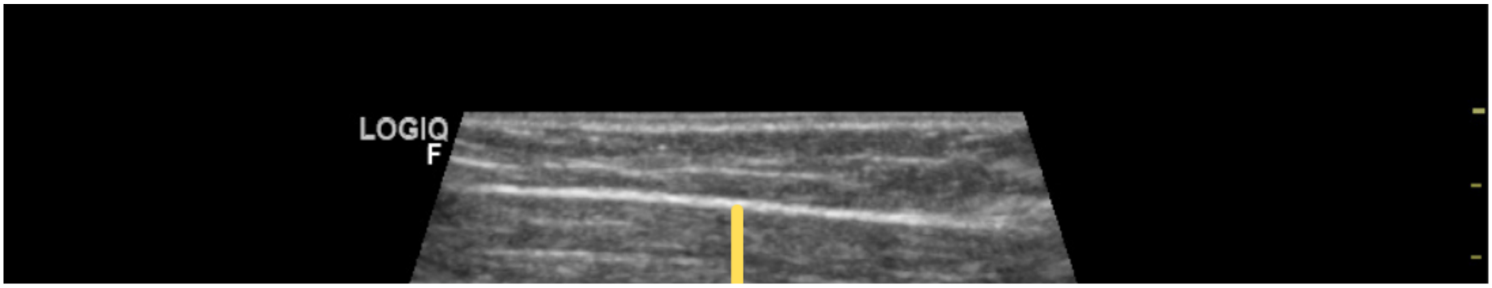

Figure 2

A representative measurement of the MT of a subject from a Ultrasound Scan

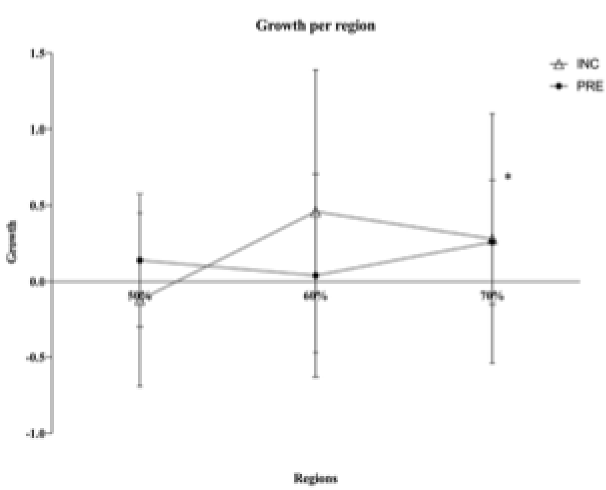

Figure 3

Muscle growth per region (in percentages)