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Comparative Analysis of B-Mode Ultrasound, Thigh Circumference, and Skinfold and Thigh-Circumference Based Cross-Sectional Area Measurements for Detecting Resistance Training-Induced Muscle Size Changes

Kadir KESKİN[1], Fatma TOKAT[2]

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ORIGINAL ARTICLE

[1]Gazi Üniversitesi, Spor Bilimleri Fakültesi, Ankara/Türkiye

[2]Erzincan Binali Yıldırım Üniversitesi, Spor Bilimleri Fakültesi, Erzincan/Türkiye

Corresponding Author:
Kadir KESKİN
kadirkeskinn94@gmail.com

Abstract

The aim of this study was to evaluate the changes in muscle mass resulting from resistance training using B-mode ultrasound, circumference measurement, and circumference-based estimation of cross-sectional area, as well as to determine the predictive value of these three measurement methods for muscle mass changes. Thirty-five young males (age: 22.14±1.37 years, body weight: 76.37±8.38 kg, height: 178.89±6.35 cm, body mass index: 23.88±2.52) with experience in resistance training and currently engaged in resistance training voluntarily participated in the study. The quadriceps muscle thickness of the participants was measured using B-mode ultrasonography, thigh circumference was measured using a measuring tape, and quadriceps skinfold thickness was measured with a caliper at the thickest point (50%). The findings obtained demonstrated that following a 20-session resistance training program, B-mode ultrasonography, thigh circumference measurement, skinfold, and circumference-based estimation of cross-sectional area (CSA) could similarly detect the changes occurring in muscle mass ($p < 0.05$). The average percentage change was 23.7% for ultrasonography, 2.6% for thigh circumference, and 2.8% for skinfold and circumference-based estimation of cross-sectional area (CSA). Correlation analysis of the average differences obtained from the three measurement methods revealed a high positive relationship between circumference measurement and skinfold-circumference-based CSA ($r = 0.826$, $p < 0.001$). In conclusion, it can be stated that changes in muscle mass resulting from resistance training can be detected similarly through anthropometric measurements and ultrasonography. However, the magnitude of muscle mass change may vary depending on the measurement method used. Therefore, when comparing the increase in muscle mass across different resistance training interventions, the measurement methods should be taken into consideration.

Key Words: Ultrasonography, Circumference Measurement, Muscle Mass, Resistance Training

Direnç Antrenmanı Kaynaklı Kas Kütlesi Değişikliklerini Tespit Etmek İçin B-Mod Ultrason, Uyluk Çevresi ve Skinfold ve Uyluk Çevresine Dayalı Enine Kesit Alanı Ölçümlerinin Karşılaştırmalı Analizi

Öz

Bu araştırmanın amacı, direnç antrenmanı kaynaklı ortaya çıkan kas kütlesindeki değişimin B-mod ultrason, çevre ölçümü, skinfold ve çevre ölçümüne dayalı enine kesit alanı kestirimi ile değerlendirilmesi ve üç ölçüm yönteminin kas kütlesindeki değişime ilişkin belirleyiciliğini ortaya koymaktır. Araştırmaya direnç antrenmanı tecrübesi olan ve direnç antrenmanına devam eden 35 genç erkek (yaş: 22.14±1.37 yıl, vücut ağırlığı: 76.37±8.38 kg, boy uzunluğu: 178.89±6.35 cm, vücut kitle indeksi: 23.88±2.52) gönüllü olarak katılmıştır. Katılımcıların kuadriceps kas kalınlığı B-mod ultrasonografi, uyluk çevresi mezura, kuadriceps deri kıvrım kalınlığı ise kaliper aracılığı ile en kalın noktadan (%50) ölçülmüştür. Elde edilen bulgular, 20 seanslık direnç antrenmanı sonucunda, B-mod ultrasonografi, uyluk çevresi ölçümü, skinfold ve çevre ölçümüne dayalı enine kesit alanı (EKA) kestiriminin kas kütlesinde meydana gelen değişimi benzer şekilde tesptit edebildiğini göstermiştir ($p < 0.05$). Ortalama değişim %'si ultrasonografi için %23,7, uyluk çevresi için %2,6, skinfold ve çevreye dayalı EKA için %2,8'dir. Üç ölçüm yöntemi ile elde edilen ortalama farkın korelasyon analizi çevre ölçümü ve skinfold-çevre ölçümüne dayalı EKA arasında yüksek düzeyde pozitif bir ilişki olduğunu göstermiştir ($r= 0.826$, $p<0.001$). Sonuç olarak, direnç antrenmanı kaynaklı kas kütlesindeki değişimin, antropometrik ölçümler ve ultrasonografi ile benzer şekilde tespit edilebildiği söylenebilir. Ancak kas kütlesindeki değişim büyüklüğü ölçüm yöntemine göre farklılık gösterebilir, farklı direnç antrenmanlarının kas kütlesindeki artışına yönelik karşılaştırmalar yapılırken ölçüm yöntemleri göz önünde bulundurulmalıdır.

Keywords: Ultrasonografi, Çevre Ölçümü, Kas Kütlesi, Direnç Antrenmanı

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Introduction

Skeletal muscle serves various essential functions in the body, including facilitating movement, maintaining posture and alignment, regulating body temperature, storing nutrients, and providing stability to joints (Wolfe, 2006). Skeletal muscle constitutes approximately 40% of the overall body mass in human individuals, encompassing a significant proportion of 50 to 75% of the total protein content within the body. They facilitate human movement and daily activities while contributing to respiratory mechanics, postural stability, balance, and protection of vital organs (Frontera and Ochala, 2015). Therefore, there is a significant interest in enhancing skeletal muscle mass to optimize physical performance and achieve aesthetic goals, with many individuals citing it as the main reason for participating in resistance training (RT). Recognizing the importance of muscle mass, a large number of people use RT as a method to stimulate skeletal muscle growth. The enlargement of skeletal muscle size through resistance exercise occurs due to an augmentation of individual muscle fibers' cross-sectional area (CSA) (Mcglory and Phillips, 2015). Various methodologies are employed to assess muscle size at distinct time points, encompassing single-time and multiple-time measurements to ascertain changes. These approaches comprise bioelectrical impedance analysis, dual-energy X-ray absorptiometry, computed tomography, magnetic resonance imaging (MRI), and B-mode ultrasound (US) (Gentil et al, 2020). Also, anthropometric measures, such as the assessment of calf and arm, thigh circumference (TC), have been explored as a method to evaluate muscular mass. (Chen et al. 2011; Gentil et al. 2020; Rolland, 2003; Qui˜nonez-Olivas, 2016).

B-mode ultrasound, gaining popularity recently, is a reliable method for assessing muscle thickness in both males and females. It has demonstrated comparable measurements to more advanced techniques like magnetic resonance imaging or computed tomography (Kuehne et al. 2019). Indeed, studies have demonstrated that B-mode ultrasound is a comparable method to MRI for tracking changes in muscular hypertrophy, leading to similar conclusions when assessing changes (Franchi 2018; Loenneke, 2019). However, circumference measurement would be a cheaper and easier alternative method than B-mode ultrasound for assessing muscle thickness. The use quations based on limb circumferences, which were adjusted for skinfold thickness, was first introduced by Dekoning et al. in 1986 and Jelliffe and Jelliffe in 1969. These equations were initially devised to estimate the cross-sectional area (CSA) of muscle and bone in specific body regions. Nevertheless, these simplistic approaches typically yielded an overestimation of approximately 15-25% compared to more advanced methodologies like computed tomography (CT) scans, as demonstrated by Heymsfield et al. in 1979, and these methods exhibited limited sensitivity to monitoring small muscle mass changes associated with training programs (Bemben et al., 2005).

Hence, the purpose of this study was to investigate the impact of employing B-mode ultrasound imaging and thigh circumference measurements on the assessment of outcomes related to resistance training. We further analyzed the longitudinal variation (pre- to post-test) using thigh circumference-based cross-sectional area (TCSA) and compared the findings obtained through ultrasound, thigh circumference, and TCSA. The study aimed to determine the capability of the three measurements to assess the development of muscle hypertrophy over time.

Method

Subjects

A total of 35 male participants, who were recreationally trained, enrolled in this study. The mean age of the participants was 22.14±1.37 years, with an average weight of 76.37±8.38 kg, height of 178.89±6.35 cm, and body mass index of 23.88±2.52. All participants had a minimum of 6 months of experience in resistance training. Individuals who had previously undergone surgical intervention or experienced lower extremity injuries were excluded from the study. Informed consent was obtained from each participant after providing a detailed explanation of the research procedures, potential risks associated with the study, and the expectations from the participants. The study was conducted in accordance with the principles outlined in the Declaration of Helsinki, and ethical approval was obtained from Gazi University Ethics Commission (04.04.2023/7).

Resistance Training

The primary objective of this study was not to determine or compare the superiority of any particular training method. Therefore, the researchers refrained from implementing a specific resistance training intervention, allowing participants to maintain their existing training routines. However, all participants engaged in at least 2 leg workouts (for quadriceps) per week for the 10 weeks after the pre-measurements. Each participant individually adjusted the training intensity according to their preferences.

Quadriceps Muscle Thickness and Thigh Circumferences and Skinfold Measurements

The ultrasound skinfold, and circumference evaluations were performed 3 days subsequent to the participants' last training session to avoid any possible cell-swelling effect. All measurements were conducted on the dominant leg (i.e., kicking leg). Following the final training session, participants received clear instructions to abstain from engaging in rigorous exercise, consuming alcohol, and using diuretic substances. The mean thigh circumference and mean skinfold thickness measurements were utilized as inputs in the regression equations formulated by Housh et al. to predict the cross-sectional area (CSA) of the quadriceps femoris muscles at the midpoint of the thigh (50%

of thigh length). The regression equation is expressed as Quadriceps muscle CSA = (2.52 × midthigh circumference [in centimeters]) - (1.25 × anterior thigh skinfold thickness [in millimeters]) - 45.13.

Muscle Thickness Assessment

The measurement of muscle thickness in the quadriceps muscle was performed using B-mode ultrasound (MyLab 70 XV, Esaote Biomedica, Genoa, Italy). A radiologist with 15 years of experience in musculoskeletal radiology measured the muscle thickness of the vastus lateralis, vastus medialis, vastus intermedius, and rectus femoris. Thickness measurements for each muscle were performed at a specific anatomical site that corresponded to the midpoint, precisely 50% of the length of the thigh. The thigh length was the distance measured between the lateral condyle of the femur and the greater trochanter. Subsequently, the measurement sites were marked using a pen. The measurements were obtained with the participants positioned in a supine position. The transducer was positioned perpendicular to the skin throughout the assessment, ensuring adequate contact with a substantial application of contact gel. Careful attention was paid to maintaining minimal pressure in order to prevent compression of the underlying muscles. The radiologist performed 3 consecutive measurements using ultrasound at the marked anatomical site for each individual quadriceps muscle. The largest and smallest of the three measurements taken were used to analyse intra-rater reliability variability and an average of the three was used for other analyses. The measurement was conducted for rectus femoris, vastus intermedius, vastus lateralis, and vastus medialis, respectively.

Thigh Circumferences and Skinfold Measurement

Thigh circumference measurements were obtained from the identical anatomical site where the ultrasound examination was performed. Measurements were acquired while the participant assumed a supine position, with the knee slightly flexed and supported by a rolled towel. While performing skinfold measurements, participants were instructed to sit on the edge of a bench, ensuring an upright posture of their torso while extending their dominant leg. Three recordings were obtained with the tape measure being removed each time, and largest and smallest of the three measurements taken were used to analyze intra-rater reliability variability an average of the three was used for other analyses. A highly experienced sports scientist conducted all measurements.

Data Analysis

Descriptive statistical measures were employed to compute the mean values and standard deviations (SD) for every testing session across all administered tests. All data were tested for normality with the Shapiro–Wilk test and for homogeneity with Levene's test. A Repeated Measures One-Way Analysis of Variance (ANOVA) was conducted on the baseline tests for each measurement method in order to assess the absence of significant differences between measurements 1, 2, and 3. The paired-sample t-test was employed to examine the pre-to-post test differences within each method. The percent change was calculeted by employing the formula ((post-test - pre-test) divided by pre-test) multiplied by 100. The intraclass correlation coefficient (ICC) indicates relative reliability, quantifying the extent of consistency and agreement between two or more variables. Following the guidelines established by (Koo and Li , 2016), the ICC and its associated 95% confidence intervals (95% CI) were calculated using a 2-way mixed-effects model, emphasizing absolute agreements. ICCs were interpreted as poor (<0.5), moderate (<0.75), good (<0.9) or excellent (>0.9). The Coefficient of Variation (CV) was calculated in SPSS for each individual, using the equation CV = (Standard Deviation/Mean) x 100. An appropriate and small CV was set to <10% (Atkinson and Nevill, 1998). The correlation for the mean change from pre to post-test between the measurement methods was evaluated using Pearson product-moment correlations. Correlations were categorized as very weak, weak, moderate, strong, or very strong based on their values falling within specific ranges: 0.00-0.19, 0.20-0.39, 0.40-0.59, 0.60-0.79, and 0.80-1.00, respectively (Papageorgiou, 2022; Weisscher, 2007). The level of significance was set at 0.05.

Results

Table 1

Descriptive Data (Mean±SD)

Age (year)	22,14±1,37
Weight (kg)	76,37±8,38
Height (cm)	178,89±6,35
BMI	23,88±2,52

BMI: Body mass index

Table 2

Baseline Intra-Rater Reliability For Quadriceps Muscle Thickness, Thigh Circumference And Skinfold Measurements (Mean±SD)

Variables	**Measure 1**	**Measure 2**	**Measure 3**	**ICC (95% CI)**	**CV% (95% CI)**	**p**
Quadriceps Muscle Thickness (mm)	68,43±6,65	67,90±8,09	69,52±10,88	0.860 (0.756-0.925)	7.3% (6.7%-7.9%)	0.386
Thigh Circumference (mm)	55,08±3,26	55,02±4,04	54,85±3,66	0.970 (0.948-0.984)	1.8% (1.6%-2%)	0.652
Thigh Skinfold (mm)	16,28±5,90	16,11±5,86	16,12±5,77	0.998 (0.996-0.999)	3.0% (2.3%-3.7%)	0.286

$P<0.05$, Descriptive (mean±SD), reliability (ICC, CV%) for the measurements of muscle thickness, thigh skinfold and circumference SD = standard deviation, ICC = intraclass correlation coefficient, 95% CI = 95% confidence intervals, CV% = coefficient of variation.

According to the ICC test, all comparisons of the different measurements presented good to excellent reliability (ICC 0.86 and > 0.90) and a small within-subject variability or typical error for the results (CV 1.8–7.3%). The one-way repeated measures ANOVA analysis showed that no significant differences were obtained within the three measurements for each method.

Table 3

Paired Samples T-Test Results For The Quadriceps Muscle Thickness, Thigh Circumference And Thigh Circumference-Based CSA (TCSA)

Variables	**Mean**	**Mean Difference**	**Change %**	**95% CI (Upper-Lower)**		**t**	**p**
Quadriceps Muscle Thickness (mm)	Pre 68,62±7,71 Post 84,94±7,74	16,32±8,31	23,7%	19,18	13,47	11,616	0.000
Thigh Circumference (mm)	Pre 54,99±3,57 Post 56,40±3,88	1,40±2,52	2,6%	2,28	,54	3,308	0.002
TCSA (cm^2)	Pre 73,26±7,78 Post 75,28±8,70	2,03± 5,34	2,8%	3,87	,19	2,237	0.032

$p<.0.05$

The results of the paired samples t-test indicated that the three distinct methods employed to assess changes in muscle mass resulting from a resistance training intervention could identify a statistically significant difference from the pre-test to the post-test.

Table 4

Pearson Product-Moment Correlation Analysis for the Average Change Observed through Thigh Circumference, Thigh Circumference -Based CSA, and B-Mode Ultrasound

Variables		**B-Mode Ultrasound**	**Thigh Circumference - Based CSA**	**Thigh Circumference**
Thigh Circumference	r	,262	,826**	1
	p	,128	,000	
B-Mode Ultrasound	r	1	,148	,262
	p		,395	,128

$p<.0.05$

Pearson product-moment correlation for the mean change (pre-to-post test) detected by three different measurements revealed that thigh circumference and thigh circumference-based CSA had a significant positive correlation. In contrast, no significant correlation was observed between thigh circumference, thigh circumference-based CSA, and B-mode ultrasound.

Discussion and Conclusion

The present study aimed to investigate the estimates of changes in muscle size as measured by three methods: B-mode ultrasonography, thigh circumference, and thigh circumference-based CSA. The paired sample t-test results showed that the three methods obtained similar results for the muscle size change after 10 weeks of resistance training. The findings of our study indicated that the three employed methods acknowledged the occurrence of a change in muscle size. The correlation analysis between thigh circumference and thigh circumference-based CSA demonstrated that individuals exhibit similar changes in these two independent measurements. However, our investigation did not reveal a significant association between the mean change detected by B-mode ultrasound and thigh-based measurements. Also, it is worth noting that the estimates of change magnitude may be greater for B-mode ultrasound, and the significance level could vary depending on the measurements employed. These findings have important implications, particularly when comparing the magnitudes of changes across different studies and when calculating summary estimates in meta-analyses involving different measurement approaches (Gentil et al., 2017; Gentil et al., 2020).

Similar to Bemben et al. (2005), who reported that thigh circumference-based measurement combined with ultrasonography could detect Kaatsu training-induced muscle hypertrophy as MRI did, our results found that the three methods can detect changes in muscle size over time. However, there could be important differences between the methods. For example, MT measurement was exclusively specific to knee extensor muscles, while TC measurement included knee flexors and extensors. Prior investigations have revealed that different muscles could potentially show dissimilar patterns of hypertrophic development over time in response to resistance training (Ogasawara et al., 2012). An alternative factor contributing to the differences in percentage changes derived from each measurement stems from the omission of subcutaneous fat influence within TC, in contrast to MT's exclusive focus on muscular components. This could pose a constraint when examining individuals with elevated adiposity levels and in studies of extended duration or those encompassing weight loss interventions. In such instances, changes in subcutaneous fat may be more pronounced, potentially resulting in an underestimation of muscular hypertrophy changes when utilizing TC (Gentil et al., 2020). Assessments conducted at singular time points, supplemented with skinfold measurements to derive estimated thigh muscle area independent of subcutaneous fat, have demonstrated robust associations and comparable reliability to MT measurements (Budzynski-Seymour et al., 2019). Moreover, the researchers observed a remarkable and statistically significant correlation between MT and TC measurements ($r = 0.831\text{-}0.918$, $p < 0.01$). The coefficient of variance exhibited similarity in reliability measurements between the two assessments, with a value of 2.3 (range: 1.6-2.4) for thigh circumference and 2.4 (range: 1.7-4.4) for quadriceps muscle thickness, respectively. Our results failed to find a correlation between thigh circumference-based-CSA and ultrasonography-measured quadriceps muscle thickness. However, and more importantly, our findings showed that both methods could detect a significant muscle thickness change from the pre-to-post test.

From a practical perspective, researchers must consider logistical feasibility when devising studies aimed at investigating muscle hypertrophy. Anthropometric measurements require minimal equipment, are easy-accessible, have simpler and faster procedures, and require less training. Conversely, ultrasonography offers the benefit of enabling the examination of individual muscles while excluding the contribution of subcutaneous fat in the analysis. Hence, researchers are strongly advised to meticulously consider their choice of methodology for their study when faced with a need for rigorous assessment. Doxey (1987) revealed that when thigh volume and circumference measurements were corrected for fat content, the correlations between anterior thigh muscle thickness and anthropometric variables improved, and also, the net circumference could account for 77.7 and 52.6% of the variance in the anterior and posterior thigh muscle thickness respectively. This study has some limitations: we conducted the study for only lower extremity muscles and in young men. Therefore, the results may not be valid for obese or overweight people. The minimal detectable change, minimal clinically important difference, or smallest worthwhile change calculations were not made for each measurement method. Future studies are warranted to include these calculations.

Conclusion

In conclusion, our data suggest that for the lower extremity TC, TCSA, and MT measurements can detect 10-week RT-induced change in muscle size. Therefore, the three methods can be considered useful for monitoring hypertrophic adaptations over time. Nonetheless, it is imperative to acknowledge that the duration of the intervention can exert an impact on the obtained results, implying that anthropometric measurements may fail to detect instances of RT-induced hypertrophy lasting fewer than 10 weeks or exhibiting lesser magnitudes of muscle hypertrophy. Considering the advantages of ease of use, cost-effectiveness, and minimal equipment requirements, the TC method may be considered a preferred choice. Using circumference-based-CSA is recommended rather than only circumference measurement.

Ethics Committee Approval Information

Ethics assessment board: Gazi University, Health and Sports Sciences Ethics Committee

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Declaration of Contribution Rates of Researchers

Authors contributed equally to the entire research process.

Conflict Statement

The authors do not declare any conflicts with the research.

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