The technical note: The use of anthropometry for assessing muscle size

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The gold standard for assessing muscle size (cross-sectional area and volume) has been magnetic resonance imaging (MRI) and computerized tomography (CT), however, these processes are very expensive and generally require a medical facility, and in the case of CT, can involve exposure to high levels of radiation. The advent of B-mode ultrasound, in conjunction with simple anthropometric measures, such as circumference, can perhaps offer a quick, valid and reliable, and cost effective method to estimate muscle cross-sectional area (CSA) and track changes in muscle CSA following training. The purpose of this study was to document the reliability and accuracy of B-mode ultrasound in combination with anthropometry for assessing Kaatsu training induced changes in muscle-bone CSA. The data from thirty-three young men (mean age, 22.2 ± 5.1 yrs) in four different training groups were combined for the statistical analysis. All subjects were assessed prior to training and three days after the last training session. Anthropometric assessment of the right thigh circumference was taken at the mid point of the thigh (between the lateral condyle of the femur and greater trochanter), and midline anterior (QAT) and posterior (HAT) measures of subcutaneous adipose tissue thickness, at the same level as the circumference measures, was obtained with B-mode ultrasound. The muscle-bone CSA was estimated with the following equation: 

\[ \text{CSA} = \pi \left( \frac{\text{circumference}}{2} \right)^2 - \left( \frac{\text{QAT} + \text{HAT}}{2} \right)^2 \]

Each subject also had their right thigh imaged, at the same point as the circumference measure, by MRI. The estimated muscle-bone CSA was on average, 21% higher than the MRI measured CSA prior to training but the two methods were significantly (p<0.01) correlated (r=0.81). The correlation between the changes in estimated and MRI measured CSA due to muscle hypertrophy following Kaatsu training was also high (r=0.86) and significant (p<0.01) and only differed on average by 1.8% between two methods. In conclusion, it appears that anthropology in combination with ultrasound can provide a reliable, accurate, and cost effective alternative method for assessing muscle hypertrophy.

Key words: B-mode ultrasound, muscle hypertrophy, muscle-bone cross-sectional area

INTRODUCTION

The ability to assess the effectiveness of different exercise interventions, like Kaatsu training, and changes in muscle CSA and volume in vivo has become increasingly important. In order to do this, methods such as the endogenous excretion of 3-methylhistadine or creatinine, whole body potassium counting, or isotope dilution with substances like deuterium oxide, can indirectly assess total muscle mass, however, radiographic techniques offer an unique opportunity for the direct visualization of specific areas of muscle that can be directly linked to muscle hypertrophy resulting from different forms of training.

CT and MRI imaging can accurately assess changes in muscle CSA and are considered the “gold standard” for assessing muscle size, however, these techniques are very expensive, involve either x-ray or radiation exposure, time consuming, and are most often located in medical facilities. These factors often preclude the use of these devices for most researchers, especially for large sample size studies and the need for frequent analyses.

In recent years, a number of publications have reported that a variety of low intensity activities, like walking or resistance training (20% of 1RM) with restriction of muscular venous blood flow, i.e., Kaatsu-Training, can result in significant and rapid (~2 weeks) increases in muscle hypertrophy (Abe et al., 2005; Takarada et al., 2000). The rapid time course of these changes need to be assessed on a daily basis and therefore would preclude the use of devices like MRI and CT imaging.

The use of equations based on limb circumferences, corrected for skinfold thickness, were first developed to estimate regional muscle-bone CSA (Dekoning et al., 1986; Jelliffe and Jelliffe, 1969), then the equations were corrected for gender (Heymsfield et al., 1982), however, these simple methods generally resulted in an overestimation of 15 - 25% when compared to more sophisticated techniques such as CT scans (Heymsfield et al., 1979) and these methods lacked the sensitivity to monitor small changes in muscle mass associated with training programs. To improve the ability and sensitivity of estimated muscle-bone CSA assessments, ultrasound has been
adapted to provide a more accurate measure of subcutaneous fat than skinfolds (Black et al., 1988; Borkan et al., 1982; Weiss, 1984; and Weiss and Clark, 1987) and new estimation equations have been developed that may provide the sensitivity to track small changes in muscle-bone CSA over short time periods with repeated measures.

Therefore, the purpose of this study was to document the validity of B-mode ultrasound for measuring subcutaneous fat and providing the ability to mathematically estimate muscle-bone CSA before and after short term training when compared to the accepted standard of MRI measures.

METHODS
Subjects

The data from thirty-three young men (mean age, 22.2 ± 5.1 yrs; mean height, 173.3 ± 6.0 cm; and mean weight, 65.1 ± 9.4 kg) in four different training groups were combined for the statistical analysis. There were two treatment groups, walk-training combined with Kaatsu (Walk-Kaatsu, n=9) and low intensity (20% OHRM) resistance exercise combined with Kaatsu (LIT-Kaatsu, n=9) and two control groups, walking control (n=8) and light resistance training control (LIT, n=7). Before testing, Institutional approval was obtained and each subject signed informed consent. Subjects did not participate in any vigorous leg or arm exercises on the days of assessment.

Estimated Muscle-Bone CSA

Each subject had their right mid thigh anthropometrically assessed with a circumference taken at the mid point of the right upper leg between the lateral condyle of the femur and greater trochanter. Subjects were then measured at the midline of the thigh, both anteriorly (QAT) and posteriorly (HAT) for subcutaneous adipose tissue thickness (AT), at the same level as the circumference measures, with B-mode ultrasound (SSD-500, Aloka, Japan). A 5-MHz scanning head was coated with water-soluble transmission gel to provide acoustic contact without depressing the dermal surface. The formula that was used to estimate the muscle-bone CSA was as follows: 

\[ \text{Muscle-Bone CSA} = \pi (r - (\text{QAT} + \text{HAT}) / 2)^2 \]

where \( r \) was the radius of the right thigh calculated as circumference \( / 2 \pi \), and QAT and HAT were ultrasound measured (Abe et al., 1994) anterior and posterior thigh adipose tissue thickness, respectively (Figure 1). This measurement was carried out prior to training (baseline) and three days after the last training session.

MRI Measured Muscle CSA

Each subject also had their right thigh imaged, at the same point as the circumference measure, by MRI (GE Signa 1.5-T scanner, T1 spin echo sequence, 256 x 256 resolution, 1 cm slice). The estimated CV for this technique has been determined to be approximately 2% (Abe et al., 2003). Subjects were assessed prior to training and then again following the various training interventions.

Statistical Analysis

All data are reported as means and standard deviations (SD). Relationships between the estimated muscle-bone CSA and MRI measured CSA of the mid thigh at baseline and between the percent changes for the two methods (post-training minus baseline / baseline) were examined using Pearson product correlations. A paired t-test was used to evaluate the mean differences between estimated muscle-bone CSA and MRI measured CSA and percent changes.

Muscle-Bone CSA = \( \pi (r - AT)^2 \)

\[ r = \text{Circumference} / 2 \pi \]

\[ AT = (\text{QAT} + \text{HAT}) / 2 \]

Figure 1. Schematic representation of the thigh CSA and the derivation of variables used to calculate the estimated muscle-bone CSA. AT, adipose tissue thickness; QAT, anterior AT: HAT, posterior AT.
between the two methods. Statistical significance was set at a probability level of p < 0.05.

RESULTS

Reliability of Estimated Muscle-Bone CSA

The mean differences between test 1 and 2 for mid-thigh circumference, ultrasound fat thickness and muscle-bone CSA were calculated as 0.6%, 0.8% and 1.2%, respectively. Therefore, these results were considered reliable and acceptable for use in this study.

Baseline Measurements of Thigh Muscle Size

On average, estimated muscle-bone CSA and MRI measured CSA were 171.3 ± 26.8 cm² and 141.4 ± 17.3 cm², respectively. The estimated muscle-bone CSA was 21% higher (p<0.01) than that of the MRI measured CSA, however, there was a significant relationship (r=0.81, p<0.01) between estimated muscle-bone CSA and MRI measured CSA (Figure 2).

Evaluation of Muscle Hypertrophy

Percent changes in muscle size were similar (p>0.05) between estimated muscle-bone CSA and MRI measured CSA in the Walk-Kaatsu group (4.9% for muscle-bone CSA and 5.3% for MRI measured CSA), LIT-Kaatsu group (8.0% and 8.5%, respectively), LIT (1.4% and 1.1%, respectively), and walk-control (-0.3% and -0.9%, respectively). There was also a strong relationship (r=0.86, p<0.01) between changes in muscle size (Figure 3) as evaluated by both the estimated (ultrasound + circumference) and measured (MRI) procedures.

DISCUSSION

It is well established that MRI can accurately determine thigh muscle CSA as well as changes in thigh CSA following training, however, the technique is prohibitive for most researchers. From a theoretical perspective, B-mode ultrasound and a circumference measure may offer a much more cost effective, yet still accurate method to assess thigh muscle CSA changes in more practical settings.

The results from this study indicate that B-mode ultrasound in combination with a circumference measure can provide accurate and reliable measures of muscle hypertrophy following Kaatsu training, however, the estimated muscle-bone CSA was overestimated by about 21% when compared with the MRI method at baseline. In other words, the ability to assess change is good with the estimated method (ultrasound + circumference) but actual values of muscle-bone CSA are overestimated. Several possibilities for the overestimation may exist. First, the mid-line anterior and posterior thigh subcutaneous fat thickness sites used in this study are usually less than other possible sites located at lateral and medial locations of the thigh, which when incorporated into the equation that is used to estimate muscle-bone CSA \( \pi (r - (QAT + HAT) / 2) \) results in an overestimation. Second, the inability to account for intramuscular fat and connective tissue with the estimated method compared to the clear images obtained with MRI which takes into account these factors. Third, the estimated muscle-bone CSA will always include bone whereas the actual measured muscle CSA by the MRI method is able to exclude the bone from the muscle CSA value. Finally, the possibility may exist that with a large subcutaneous fat layer around the thigh; a higher

![Figure 2](image-url)  
**Figure 2.** Relationship between estimated muscle-bone CSA and MRI measured CSA procedures prior to training (baseline).

![Figure 3](image-url)  
**Figure 3.** Relationship between changes in muscle size as evaluated by the estimated (circumference + ultrasound) and measured (MRI) procedures following training.
ultrasound probe pressure may compress the fat and result in an underestimation of the adipose tissue layer which would result in an overestimation of total muscle-bone CSA. Therefore care must be taken when obtaining measures of subcutaneous adipose tissue thicknesses with ultrasound to ensure proper technique is used and reliable data obtained (Abe et al., 1994; Armellini et al., 1990; Bellisari et al., 1993). Even with the numerous potential reasons for the overestimation of the muscle-bone CSA method, it should be pointed out that the overestimation reported in this study compares favorably with previously published results (Heymsfield et al., 1979).

However, the estimated muscle-bone CSA that is obtained with the ultrasound and circumference measure can still provide a valid measure of muscle hypertrophy, especially following Kaatsu training because the short duration of the intervention ensures that the shape of the muscle and the muscles relationship to the layer of subcutaneous adipose tissue for any given individual would not be altered. Therefore, in conclusion, B-mode ultrasound that can accurately measure subcutaneous adipose tissue thickness from reflected ultrasound waves, in combination with a circumference measure appears to be able to provide an safe, easy, accurate, more cost effective, and reliable alternative method for measuring changes in muscle-bone CSA, at least for the thigh when compared to MRI measurements.

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