Use of Diagnostic Ultrasound for Assessing Muscle Size

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ABSTRACT

The typical “gold standard” for assessing muscle size has been magnetic resonance imaging (MRI) and computerized tomography; however, these processes are very expensive and generally require a medical facility. The advent of B-mode diagnostic ultrasound (US) can perhaps offer a quick, cost-effective method to measure muscle size. The purpose of this study was to document the reliability of B-mode US for assessing muscle size in a variety of populations. Thirty-eight postmenopausal women (avg. age = 58.9 ± 0.7 years) had both their right rectus femoris and biceps brachii imaged, 85 older men and women (avg. age = 65.0 ± 0.4 yrs) had their right rectus femoris imaged, and 10 young men and women (avg. age = 26.1 ± 2.4 yrs) had their right rectus femoris imaged by both US and MRI. The location used for imaging on the right rectus femoris was a point 15 cm above the superior border of the patella following the midline of the anterior surface of the thigh, whereas the biceps brachii was measured at maximal girth following the midline of the anterior surface of the upper arm. All trials utilizing US (Fukuda Denshi, model 4500) and a 5 Mz transducer (FUT-L104) were obtained in duplicate on 2 separate days. The young subjects that also had their rectus femoris measured by MRI were imaged with a Picker 1.5 Tesla (The Edge), which used a fast spin sequence and 192 × 256 resolution to obtain 2.5-mm-thick slices separated by a 1-mm-thick space. All intraclass correlation coefficients for the various groups and muscles measured by US ranged from $r = 0.72-0.99$, whereas coefficients of variation (CVs) ranged between 3.5% and 6.7%. The intraclass correlation for the MRI images was $r = 0.90$ and the CV was 5.2%. In conclusion, it appears that diagnostic US can provide a reliable and cost-effective alternative method for assessing muscle.

Key Words: muscle size assessment, technology, soft tissue imaging, muscle cross-sectional area


Introduction

The ability to assess the effectiveness of different exercise interventions and changes in muscle size in vivo has become increasingly important for a variety of populations, ranging from young athletes to previously sedentary elderly currently engaged in resistance training. To do this, methods such as the endogenous excretion of 3-methylhistadine or creatinine can indirectly assess total muscle mass; however, radiographic techniques offer a unique opportunity for the direct visualization of specific areas of muscle that can be directly linked to muscle hypertrophy resulting from resistance training.

The estimation of regional muscle mass was initially obtained with anthropometric measures of limb circumferences corrected for subcutaneous adipose tissue (8, 16). This simple method generally results in an overestimation of 15–25% when compared with more sophisticated techniques such as computed axial tomography (13). Subsequent improvements were made to this anthropometric technique by developing gender-specific equations (12); however, large errors of overestimation can still be expected. Another problem with this anthropometric method is the lack of sensitivity to monitor small changes in muscle mass associated with training programs.

To be able to better quantify regional or individual muscle responses to a training stimulus, radiographic techniques were developed for the direct visualization of muscle. Three radiographic techniques currently dominate the literature with their ability to differentiate body composition parameters such as muscle, bone, and fat. These 3 measures include dual energy x-ray absorptiometry (DXA), computed tomography (CT), and magnetic resonance imaging (MRI).

Although DXA was originally developed for the assessment of bone, it can also be used to assess the soft tissue component of the body, which is composed of fat and fat-free tissue. Besides whole-body measures of fat and fat-free tissue, this technique can also be used for the regional determination of body composition with very good relations being established between this technique and measures from total body potassium ($r = 0.94$) and total body nitrogen ($r = 0.78$) (14). The one major limitation of this technique, be-
sides the cost of the equipment, is its lack of ability to assess changes to specific muscles.

CT and MRI can accurately assess changes in muscle cross-sectional area of specific muscles or muscle groups and are considered the “gold standard” for assessing muscle size. However, these techniques are very expensive, time consuming, and are most often housed in special areas within a hospital setting. These factors often preclude the use of these devices for most researchers, especially for large sample size studies.

Ultrasound (US) techniques were initially used to assess the thickness of either deposits of fat, perhaps to provide an alternative method for skinfolds, or the thickness of skeletal muscle (5, 7, 11, 15, 18, 21, 22). However, advances in US technology and the development of portable B-mode (image-producing) instruments that can construct cross-sectional images of muscle from reflected US waves may be able to provide an alternative method for measuring changes to specific muscles or muscle groups (3, 11, 17, 19, 20). In fact, Ikai and Fukunaga (15) were the first to report on the use of US to measure muscle cross-sectional areas.

These measures offer the potential to be safe, quick, and much more cost effective. However, care must be taken when using this technique, because it is subject to a number of potential measurement errors, especially if the technician or sonographer is inexperienced or not careful.

The purpose of this study was to document the reliability of B-mode ultrasonography for measuring muscle cross-sectional area over repeated trials and days for a variety of populations and 2 different muscle groups.

Methods

Subjects
Three different groups of subjects volunteered for this study. Before testing, Institutional approval was obtained and each subject then signed informed consent. Subjects did not participate in any vigorous leg or arm exercises on the days of assessment.

The first group of subjects consisted of 38 postmenopausal women (avg. age = 58.9 ± 0.7 years) who had both their right rectus femoris and biceps brachii imaged with US; the second group of subjects was composed of 85 older men and women (avg. age = 65.0 ± 0.4 years) who had only their right rectus femoris imaged with US; and the last group of subjects consisted of 10 young men and women (avg. age = 26.1 ± 2.4 years) who had their right rectus femoris imaged by both US and MRI.

Equipment
The US equipment used in this study was the Fukuda Denshi (Redmond, WA) model 4500 (Figure 1). It was used in conjunction with a 5-MHz linear transducer (FUT-L104) and a Mitsubishi P90 videocopy processor (Figures 2 and 3).

The subjects that were measured by MRI were imaged with a Picker 1.5 Tesla (The Edge), which used a fast spin sequence and 192 x 256 resolution to obtain 25-mm-thick slices separated by a 1-mm-thick space. Two separate trials on the same day were obtained by this technique. The images were also obtained at the same location on the upper thigh as were imaged by the US technique.
Measuring Muscle Cross-Sectional Area

Figure 3. This photo shows the Fukuda Denshi model 4500 B-mode ultrasound and the track ball that is used for tracing the image of the muscle to calculate muscle cross-sectional area.

Calibration

Quality assurance, or the procedures used to monitor instrument accuracy and image quality, were checked before data collection using a multipurpose ‘phantom’ or standard (Nuclear Associates 84-317; Carle Place, NY). This phantom uses a water-based polymer as the tissue-mimicking material. Present within the phantom were internal components, filaments and cylinders, with known dimensions and spacings. Filaments are typically strands of nylon fiber (0.1 to 0.15 mm in diameter) arranged in rows or groups, whereas cylinders are tubes (2 mm in diameter or larger). The attenuation of the phantom (typically 0.5 to 0.7 dB·cm\(^{-1}\)·MHz) is controlled during the manufacturing and the speed of sound through the phantom was approximately 1,540 m·s\(^{-1}\).

Several steps are taken during the quality assurance procedure. First, maximum penetration and system sensitivity are checked by scanning the vertical filament group from the top of the phantom. This assessment is based on the distance where scattering echoes disappear and the distance to the last visible filament echo. Next, axial and lateral resolution were checked by determining the distance between the 2 closest filaments that can be resolved along each group axis in each resolution group. The axis that is parallel to the beam axis is used for the axial resolution and the axis that is perpendicular to the beam axis is used for the lateral resolution estimates.

To determine the ‘dead zone’, or the distance from the transducer face to the first identifiable echo, the dead zone filament group of the phantom is scanned from the top surface to the most anterior visible rod. Finally, the electronic caliper accuracy is checked along with the vertical and horizontal linearity. Both vertical and horizontal filament groups are scanned and the electronic scale is checked against actual distances between the filaments. The vertical electronic calipers have generally been used to measure tissue thicknesses in previous studies (19).

Limb Positioning

To obtain a cross-sectional area assessment for the right rectus femoris muscle, subjects were placed in a supine position with a rolled-up towel under the popliteal fossa. The towel allowed for about a 10° bend at the knee, which helped ensure that the upper thigh was relaxed. To locate the exact evaluation site, the upper border of the patella was marked with a pen; then a point 15 cm above the mark following the midline of the anterior surface of the thigh was also marked. It was determined that by choosing a standard distance away from a boney landmark, better reproducibility could be maintained.

Because US can be used to follow changes to the rectus femoris over time (within each individual subject), then using a common distance from the top of the patella is an acceptable method. By following changes within subjects, each subject actually acts as their own control or comparison. No attempt was made to obtain the same absolute position on the rectus femoris for the different subjects since this is a much more difficult assessment and was not of interest for the current study.

For subjects who were measured for the biceps muscle cross-sectional area, they were also placed in a supine position with their right arm supported with the shoulder in 80° of abduction and the elbow slightly flexed. These measures of cross-sectional area were obtained at the greatest girth of the upper arm, following the midline of the anterior surface of the upper arm. All trials utilizing US (Fukuda Denshi, model 4500) and a 5-MHz transducer (FUT-L104) were obtained in duplicate on 2 separate days.

Image Tracing

All US imaging trials used a water-soluble transmission gel to help image the rectus femoris or biceps brachii muscle. Once the image was located on the monitor (cathode-ray tube), the image was ‘frozen’ (Figure 4). Care was taken to ensure that the transducer was always placed perpendicular to the anterior surface of the thigh or upper arm and that no depression of the skin surface occurred. Then using the cross-sectional area trace calculation procedure and the track ball, the muscles were traced along the inner edge fibrous sheath (Figure 5).

The processed MRI images were measured for cross-sectional areas by both the technical staff associated with the MRI unit and also by the same technician that obtained the US scans.

Cross-Sectional Area Calculation

Once the ‘area-T’ option is selected, a “+” caliper mark appears on the screen. Then, by moving the mark with the aid of the track ball, and pressing “mark set,” the start position for the tracing is established. As noted on Figure 5, the value with the + in
Figure 4. Image of the rectus femoris, obtained at the 15 cm position above the top border of the patella, before the imaging technique.

front of it (4.3 cm²) is the calculated cross-sectional area. The internal procedures for calculating muscle cross-sectional area were approved by the American Institute of Ultrasound and Medicine, as well as by the Food and Drug Administration.

Statistical Analyses
The statistical analyses were carried out on SPSS® for Windows Version 9.0. All data are reported as means and standard errors. To determine the reliability for both the US and MRI images, intraclass correlation coefficients were determined across trials and days from a repeated-measures analysis of variance (10). Coefficients of variation (CVs) were calculated for both techniques by expressing the variability of each measure (standard errors) by the mean of the measure and multiplying by 100 (CV = \([\text{SEM/mean}] \times 100\)). Statistical significance was set at a probability level of \(p \leq 0.05\).

Results
Table 1 displays the descriptive characteristics for each group of subjects in this study, whereas Table 2 presents the mean cross-sectional areas for the rectus femoris and biceps brachii for each group and both assessment techniques. No significant within-day mean differences \((p > 0.05)\) existed; therefore all trials within a given day were averaged and then compared across days. All measures were similar across days. The intraclass correlation coefficients ranged from \(r = 0.72\) \((p < 0.01)\) to \(r = 0.99\) \((p < 0.01)\), whereas CVs were less than 6.7% (Table 3).

Discussion
It is well established that MRI can accurately determine muscle cross-sectional area; however, the technique is prohibitive for most researchers. From a theoretical perspective, B-mode US may offer a much more cost-effective method to assess muscle mass; however, previously proposed US methods for quantifying both fat and muscle mass have used thickness measures instead of cross-sectional areas (1, 2, 4–7, 9, 11, 18, 21, 22). Muscle cross-sectional areas are comparatively more desirable than muscle thickness measures because of the better relation to muscle hyper-
### Table 1. Descriptive characteristics for each group of subjects.

<table>
<thead>
<tr>
<th>Group</th>
<th>n</th>
<th>Gender</th>
<th>Age (yrs)</th>
<th>Height (cm)</th>
<th>Weight (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Postmenopausal</td>
<td>38</td>
<td>Female</td>
<td>58.9 ± 0.7</td>
<td>163.3 ± 1.1</td>
<td>70.7 ± 1.1</td>
</tr>
<tr>
<td>Older</td>
<td>51</td>
<td>Female</td>
<td>64.4 ± 0.5</td>
<td>163.7 ± 0.9</td>
<td>67.3 ± 1.5</td>
</tr>
<tr>
<td>Older</td>
<td>34</td>
<td>Male</td>
<td>65.2 ± 0.6</td>
<td>173.3 ± 1.4</td>
<td>86.4 ± 2.9</td>
</tr>
<tr>
<td>Young</td>
<td>5</td>
<td>Female</td>
<td>26.0 ± 3.5</td>
<td>170.1 ± 1.1</td>
<td>63.4 ± 3.9</td>
</tr>
<tr>
<td>Young</td>
<td>5</td>
<td>Male</td>
<td>26.2 ± 3.7</td>
<td>174.6 ± 1.2</td>
<td>84.1 ± 4.8</td>
</tr>
</tbody>
</table>

* Values are mean ± standard error.

### Table 2. Muscle cross-sectional areas for each group, muscle, and technique.

<table>
<thead>
<tr>
<th>Group</th>
<th>n</th>
<th>Gender</th>
<th>US—rectus femoris (cm²)</th>
<th>MRI—rectus femoris (cm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Day 1</td>
<td>Day 2</td>
</tr>
<tr>
<td>Postmenopausal</td>
<td>38</td>
<td>Female</td>
<td>3.48 ± 0.12</td>
<td>3.49 ± 0.14</td>
</tr>
<tr>
<td>Older</td>
<td>51</td>
<td>Female</td>
<td>2.99 ± 0.12</td>
<td>2.84 ± 0.12</td>
</tr>
<tr>
<td>Older</td>
<td>34</td>
<td>Male</td>
<td>4.05 ± 0.18</td>
<td>4.06 ± 0.19</td>
</tr>
<tr>
<td>Young</td>
<td>5</td>
<td>Female</td>
<td>5.02 ± 0.41</td>
<td>5.34 ± 0.52</td>
</tr>
<tr>
<td>Young</td>
<td>5</td>
<td>Male</td>
<td>5.22 ± 0.61</td>
<td>5.48 ± 0.54</td>
</tr>
</tbody>
</table>

* Values are mean ± standard error. US = ultrasound; MRI = magnetic resonance imaging; Tr = trial.

### Table 3. Intraclass correlation coefficient for each group, muscle, and technique.

<table>
<thead>
<tr>
<th>Group</th>
<th>n</th>
<th>US</th>
<th>MRI</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Rectus Femoris</td>
<td>Biceps Brachii</td>
</tr>
<tr>
<td>Postmenopausal</td>
<td>38</td>
<td>0.88 (3.8%)</td>
<td>0.99 (3.6%)</td>
</tr>
<tr>
<td>Older</td>
<td>85</td>
<td>0.72 (3.5%)</td>
<td>—</td>
</tr>
<tr>
<td>Young</td>
<td>10</td>
<td>0.80 (6.7%)</td>
<td>0.90 (5.2%)</td>
</tr>
</tbody>
</table>

* (Coefficient of variation.)

Trophy and force-producing characteristics associated with muscle size.

The results from this study indicate that B-mode diagnostic US can provide reliable cross-sectional area measures of a superficial muscle (rectus femoris or biceps brachii); however, care must be taken when obtaining measures of muscle size with this technique since there are a variety of potential sources of measurement error (such as compression of the skin tissue or possible distortion of the image if the transducer deviates from a perpendicular orientation to the long axis of the limb being assessed). Because care and expertise is needed for this technique, it is recommended that only skilled technicians should use US for the purpose of assessing muscle size.

In the small sample of young subjects, data obtained with the diagnostic US was significantly correlated with the muscle cross-sectional areas obtained with MRI and there were no significant mean differences between the 2 techniques; however, there was a larger CV for the US measures.

### Practical Applications

As mentioned earlier, CT and MRI are considered the gold standard for assessing muscle size; however, the cost and limited access to these techniques preclude the use of these devices for most researchers.

B-mode US instruments that can construct cross-sectional images of muscle from reflected US waves appear to be able to provide an alternative method for measuring muscle size, at least for muscles that are superficial and easily accessible such as the biceps brachii and rectus femoris. The use of US is safe, quick, and much more cost effective when compared with CT scans or MRI. However, even though US can provide a measure of muscle size, care must be taken when using this technique since it is subject to a number of potential measurement errors. Errors can arise if there is excess compression of the skin tissue from the transducer, or there can be possible distortion of the image if the transducer deviates from a perpendicular orientation to the long axis of the limb that is being assessed. These sources of measurement error necessitate the use of extreme care by the technician or sonographer when imaging a specific muscle site.

### References


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