EVALUATION OF A SIMPLE METHOD FOR DETERMINING MUSCLE VOLUME IN VIVO

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INTRODUCTION

The assessment of muscle architecture \textit{in vivo} is an important way to augment the more detailed knowledge of muscle which can be obtained from muscle architecture in cadavers. Modern imaging methods make the measurement of various aspects of muscle architecture \textit{in vivo} feasible but data collection and processing can both be time consuming. Albracht \textit{et al}. [1] suggested that muscle volume can be estimated from measurements of muscle cross-sectional area and muscle belly length only, thus reducing the time for data collection and processing. This method was evaluated by Mersmann \textit{et al}. [2] for the Triceps Surae, where muscle volumes were estimated with errors less than 8.5\% of the criterion magnetic resonance imaging determined values.

It was the purpose of this study was to further evaluate this method for the determination of muscle volume based on a limited set of measurements. It extends the analysis of Mersmann \textit{et al}. [2] in four ways,
1. It examines two different muscles, the Vastus Lateralis and First Dorsal Interosseous.
2. It uses direct measurement of muscle volume using cadaver dissection.
3. Uses the more generally available method of ultrasound to estimate muscle cross-sectional area and muscle length.
4. Uses a statistically optimal procedure for the estimation of the scaling parameter required in the method.

METHODS

Two sets of muscles were analyzed: the human First Dorsal Interosseous (FDI), and Vastus Lateralis (VL).

The cross-sectional area and length of the FDI was imaged using ultrasound in 22 cadaver hands (mean age at death: 64 years \pm 18, mean height: 172 cm \pm 8). The FDI muscles were scanned using a 7.5 MHz ultrasound probe (SSD-1000, Aloka, Japan) in B-mode. To enhance FDI image quality, by decreasing echo reverberations, a stand-off pad (2 cm thick and 9 cm in diameter) and a small amount of ultrasound gel was used. Following ultrasound scanning, the FDI muscles were dissected from the hand. Muscle volume of the FDI was determined using the water displacement technique; prior to testing it was ensured the water and muscle were at the same temperature. Test objects ranging in volume from 1 mL to 10 mL were measured in the apparatus with an accuracy of estimation of 0.01 \pm 0.01 mL.

The cross-sectional area and length of the VL was imaged using ultrasound in 8 cadaver legs (mean age at death: 64 years \pm 12, mean height: 171 cm \pm 11). In a similar fashion to the FDI the muscles of the VL were scanned prior to dissection and determination of muscle volume via underwater weighing.

To estimate muscle volume the following equation was used [1, 2],

$$V_m = p \times ACSA \times L_m$$

Where $V_m$ – muscle volume, $p$ – scaling parameter, ACSA - muscle anatomical cross-sectional area, and $L_m$ is the muscle belly length. Given the cadaver measurements the scaling parameter must be estimated for each of the muscles. To estimate the scaling parameter a robust linear regression was performed using a bivariate least squares method [3, 4]. This approach accounts for their being errors influencing both variables ($V_m$, and the product of ACSA and $L_m$) rather than assuming one variable is error free.
The sample size was small for the VL (n=8), therefore to circumvent the problem of model evaluation when there are no additional data with which to evaluate the model a cross-validation procedure was used [5]. An unbiased estimate of error was obtained by calculating the scaling parameter for sub-sets of the complete data set; the sub-set was achieved by removing one of the cadaver samples from the original data set; these removed values then served as an independent sample on which to evaluate error. By doing this sequentially for each of the muscles in turn it was possible to get multiple estimates of error from which a mean value was then computed. In addition Bland-Altman plots were also used to assess the model [6].

RESULTS AND DISCUSSION

The two sets of muscles analyzed, VL and FDI, reflect muscles of contrasting sizes (Table 1), and are representative of the larger and smaller muscles which are found in the human body [7].

Table 1: Means (± standard deviation) of length, anatomical cross-sectional area, and volume of the two sets of muscles analyzed.

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<tr>
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<th>VL</th>
<th>FDI</th>
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<tbody>
<tr>
<td>Length (cm)</td>
<td>8.5 ± 1.5</td>
<td>5.7 ± 0.7</td>
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<tr>
<td>ACSA (cm²)</td>
<td>33.8 ± 3.28</td>
<td>1.73 ± 0.40</td>
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<tr>
<td>Volume (mL)</td>
<td>239.4 ± 23.2</td>
<td>4.5 ± 1.0</td>
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For the VL the percentage root mean square error in the estimation of muscle volume was 5.0%. In the Bland-Altman plot all volume estimates were within the 95% confidence interval, with no proportional bias or relative bias in the volume estimates (p > 0.05); indicating no change in measurement accuracy with size of specimen, or the presence of a constant deviation in all estimate measures compared with the criterion. For the FDI the percentage root mean square error in the estimation of muscle volume was 18.8%. The results for the Bland-Altman plot had some predictions outside of the 95% confidence interval and the presence of proportional bias (Figure 1).

CONCLUSIONS

The results of the current study suggest that with two measures of muscle dimensions, ACSA and length, ultrasound can be used for the estimation of muscle volume for the VL but not the FDI. Other simplified approaches should be explored for the FDI. Such analysis might be useful for tracking the changes in muscle volume of the VL with aging [8], or tracking the changes due to strength training [9]. Such applications of this method warrant further examination.

REFERENCES