Interrater reliability of muscle tone, stiffness and elasticity measurements of rectus femoris and biceps brachii in healthy young and older males

Sandra Agyapong-Badu, Lucy Aird, Louise Bailey, Kate Mooney, James Mullix, Martin Warner, Dinesh Samuel, Maria Stokes

Abstract

Purpose: To examine interrater and within-session reliability of using the MyotonPRO device for measuring non-neural tone and mechanical properties of the rectus femoris and biceps brachii muscles in healthy young and older adults.

Methods: Forty-two healthy males were studied: n=21 aged 25.9 (SD 4.4) years and n=21 aged 72.1 (SD 4.9) years. The MyotonPRO device applied brief, low force mechanical impulses to the muscle belly to produce damped oscillations of the muscle at rest. Computing of the parameters was made automatically from the oscillation curve of non-neural mechanical tone (state of intrinsic tension) measured as frequency [Hz], dynamic stiffness [N/m] and elasticity (logarithmic decrement).

Analysis: The means and standard deviations of all three parameters for each rater were calculated. Reliability was assessed using intra-class correlation coefficients (ICCs) and Bland and Altman analysis.

Results: Excellent within-session intra-rater reliability was demonstrated by raters for both participant groups (intraclass correlation coefficients, ICC 3,2 = 0.94-0.99). Interrater reliability was excellent for all rectus femoris parameters in the young (ICC 3,1= 0.92-0.95) and older group (0.86-0.94). In biceps brachii, reliability was excellent in the young group (0.78-0.94) and for elasticity in the older group (0.89) but was only classed as good for tone (0.67) and stiffness (0.68).

Conclusions: Different raters obtained acceptably similar results for all three parameters of rectus femoris in both age groups and for biceps brachii in the young group, and for elasticity only in the older group. The findings indicate that the MyotonPRO has potential use for objective assessment of mechanical muscle properties in clinical and research settings and that the protocol for locating the site for testing biceps brachii in older participants could be modified to improve reliability.

Implications: The MyotonPRO device can be used reliably by different users to assess muscle parameters in healthy people of different ages. Further studies are needed to add to the existing literature to establish Myoton technology as a valid and reliable clinical and research tool for examining the effects of injury, disease and interventions in various muscles in clinical conditions.

Keywords: Quadriceps, Biceps Brachii, Mechanical properties, Muscle tone, Myoton technology, Reliability

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Acknowledgments
The authors thank staff and students of the University of Southampton and residents in the local community for taking part in the study, Dr Peter Nicholls for statistical advice, the Ghana Education Trust Fund for sponsoring SAB, Faculty of Health Sciences, University of Southampton for PhD studentship (SAB), Myoton AS (Estonia) and Myoton Ltd London for providing the MyotonPRO and Aleko Peipsi (CEO, Myoton AS Estonia) for training. There were no conflicts of interest within the present study, which was conducted independently of the company providing the equipment.

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INTRODUCTION

Clinical assessments of skeletal muscle tone and mechanical properties are often subjective. This limits their value for comparisons between groups or to population norms, as well as for monitoring the effects of medical or therapeutic treatment. Research into tone and mechanical properties of skeletal muscles has utilised sophisticated techniques, such as magnetic resonance elastography, ultrasound imaging, torque, ramp and hold, and pendulum (electrogoniometric) tests (Dresner et al. 2001), as well as electro-physiological tests to examine the neural component of muscle tone, including H-reflex, H:M ratio, electromyographic ratio to length change, and F wave measurements (Leonard et al. 2003). Although these techniques provide robust, objective measures of various muscle characteristics, they are not suitable for routine clinical use or testing in community settings, as they are expensive, labour and time intensive, and require specialized staff training. Myoton technology (Myoton AS, Estonia and Myoton Ltd London) offers an in vivo, clinical, non-invasive measurement of state of tension and some of the mechanical properties of skeletal muscle, with the added advantage of portability and is relatively inexpensive (Gavras et al. 2007; Veldi et al. 2004).

The MyotonPRO device elicits oscillations of muscle after a probe applies a brief mechanical impulse (tap) at a predetermined frequency (1.8%) and stiffness (1.7%). The mechanical impulse from the probe, using a non-toxic skin care product, approximately the diameter of the probe, using a non-toxic skin marker (Aarrestad et al. 2004). The MyotonPRO device has a testing end (probe) that is applied under constant pre-load (0.18 Newtons) to pre-compress subcutaneous tissues. The probe then exerts a brief (15 milliseconds) mechanical impulse (tap) at a predetermined force (0.4N) followed by quick release, inducing dampened natural oscillations of the muscle. The device records these oscillations (acetylthionine) over a 2 second period and performs subsequent simultaneous computation of tissue parameters. These include its state of tension or non-neural tension, characterized by frequency (Hz; F=1/τ) computed from the signal spectrum by Fast Fourier Transform; the higher the frequency the higher the muscle tone. The mechanical properties include stiffness (N/m), indicating the muscle’s ability to resist an external force that modifies its shape (the higher the value the greater the stiffness), and elasticity, characterized by logarithmic decrement, indicating ability of the tissue to recover its shape after being deformed, the higher the value, the lower the amount of mechanical energy lost during a single oscillation cycle (Masi et al. 2010; Ozkaya et al. 1999). The initial sampling rate of the device is 3200Hz and average accuracy of the measurement series (coefficient of variation) for each parameter is: frequency (0.62%), decrement (1.8%) and stiffness (1.72%). The mechanical impulse from the oscillation is then used to determine the mechanical properties of the tissue and muscle.
The earlier Myoton prototypes contained a single axis accelerometer which required that the device be held vertical (±15 degrees) to the gravity vector to obtain an accurate reading. The MyotonPRO has a triaxial accelerometer and a system which allows multidirectional measurements in relation to the gravity vector. The probe is held perpendicular to the skin surface to ensure that the energy from a mechanical impulse goes to the muscle maximally and constantly. However, due to the fact that muscle tissue is affected by gravity, it is recommended that recordings are made with the device held between 0-90 degrees to the gravity vector (keeping the end of the probe perpendicular to the skin). This ensures that the muscle is not hanging without support beneath it, such as bone, so that oscillations can be elicited effectively for testing. The device was used in multiscan mode consisting of 10 single measurements, at one second intervals, of the device provided by Myoton (AS Estonia) and a half day session on use of the device provided by Myoton (AS Estonia) and a half day session with research colleagues to develop and agree testing protocols. Rater 1 tested both muscles in all participants. Raters 2 and 3 collected data for RF in young and older participants respectively. Data for BB were collected by Raters 4 and 5 in the young and older participants respectively. The results of raters 2, 3, 4 and 5 were compared with those of Rater 1. Only the recording technique was compared between raters and not the relocation of the anatomical testing site.

**Table 1** Absolute values for tone, stiffness and elasticity for both raters

<table>
<thead>
<tr>
<th>Muscle</th>
<th>P</th>
<th>Rater</th>
<th>Young Males n=21</th>
<th>Older Males n=21</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>M1(SD)</td>
<td>M2(SD)</td>
</tr>
<tr>
<td>BB</td>
<td>1</td>
<td>Tone (Hz)</td>
<td>14.7(0.7)</td>
<td>14.7(0.8)</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td></td>
<td>14.7(0.9)</td>
<td>14.8(0.9)</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>Stiffness (N/m)</td>
<td>223(26)</td>
<td>224(26)</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td></td>
<td>227(28)</td>
<td>225(28)</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>Elasticity (D Log)</td>
<td>1.08(0.1)</td>
<td>1.07(0.1)</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td></td>
<td>1.06(0.1)</td>
<td>1.01(0.1)</td>
</tr>
<tr>
<td>RF</td>
<td>1</td>
<td>Tone (Hz)</td>
<td>16.1(1.1)</td>
<td>16.1(1.2)</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td></td>
<td>15.3(0.9)</td>
<td>15.3(0.9)</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>Stiffness (N/m)</td>
<td>288(23)</td>
<td>288(23)</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td></td>
<td>276(20)</td>
<td>276(20)</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>Elasticity (D Log)</td>
<td>1.38(0.2)</td>
<td>1.37(0.2)</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td></td>
<td>1.31(0.2)</td>
<td>1.29(0.2)</td>
</tr>
</tbody>
</table>

**RESULTS**

Absolute values for tone, stiffness and elasticity

The mean and standard deviations of the three measured parameters are presented for both sets of raters for each muscle in Table 1. Agreement between raters was assessed using Bland and Altman analysis, providing mean difference ($\overline{d}$) and 95% confidence intervals (CI), and plots to visually observe the level of agreement and allow easy identification of bias and outliers.

In the present study the following scale was used to interpret reliability: excellent > 0.75, good to fair 0.4-0.74, poor < 0.4 (Fleiss 2007). Standard errors of measurements (SEM) were also calculated using the following formula, where SD is the pooled standard deviation and ICC is the reliability coefficient (Portney and Watkins 2000).

$$SEM = SD\sqrt{1-ICC}$$

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$$SEM = SD\sqrt{1-ICC}$$
inter-rater reliability between raters for tone, stiffness and elasticity.

<table>
<thead>
<tr>
<th>Muscle</th>
<th>ICC3,1</th>
<th>95% CI</th>
<th>SEM</th>
<th>ICC3,1</th>
<th>95% CI</th>
<th>SEM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Young Males (n=21)</td>
<td></td>
<td></td>
<td></td>
<td>Older Males (n=21)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tone (F; Hz)</td>
<td></td>
<td></td>
<td></td>
<td>Tone (F; Hz)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>BB Rater 1</td>
<td>0.97</td>
<td>0.98 - 0.95</td>
<td>0.99</td>
<td>0.99</td>
<td>0.99 - 0.99</td>
<td>0.98</td>
</tr>
<tr>
<td>Rater 2</td>
<td>0.99</td>
<td>0.99 - 0.99</td>
<td>0.99</td>
<td>0.99</td>
<td>0.99 - 0.99</td>
<td>0.99</td>
</tr>
<tr>
<td>RF Rater 1</td>
<td>0.99</td>
<td>0.99 - 0.98</td>
<td>0.99</td>
<td>0.99</td>
<td>0.99 - 0.99</td>
<td>0.99</td>
</tr>
<tr>
<td>Rater 2</td>
<td>0.99</td>
<td>0.99 - 0.99</td>
<td>0.99</td>
<td>0.99</td>
<td>0.99 - 0.99</td>
<td>0.99</td>
</tr>
</tbody>
</table>

F = Frequency (Hz); D Log = Logarithmic Decrement; BB = Biceps Brachii; RF = Rectus Femoris

as good for tone (0.67) and stiffness values between raters were
ness (0.68). Overall, across both high. Examples of Bland and Alt-
muscles and groups, elasticity produced the most consistently robust
agreement between raters for results (ICC 0.78-0.95). The SEM
values in Table 3 give an indication of the degree of variability in the
each measured parameter.

Mean differences and limits of agreement

The present study demonstrated excellent reliability by novice users of
agreement for Bland and Alt-
man plots (inter-rater reliability) of the MyotonPRO device for test-
ning the tone, stiffness and elasticity using the MyotonPRO proved to be excellent according to criteria for ICC levels by Fleiss (2007) and clinically useful (ICCs >0.9) according to Portney and Watkins (Portney and Watkins 2000). Intrarater reliability for measuring all three parameters of the RF muscle was equally robust in younger males. For older males, all RF parameters were excellent, with tone and stiffness ICCs >0.9 and elasticity 0.86. Overall, logarithmic decrement, as an indication of muscle elasticity, which is its ability to recover its shape (Özkaya et al. 1999), demonstrated the most consistently robust reliability of the three parameters studied (ICCs 0.78-0.95), across the two muscles and age groups. It is worthy of note that despite tone and stiffness of BB measurements in older males demonstrating good intrarater reliability (ICC 0.68 and 0.67 respectively), elasticity showed excellent reliability (0.89). Furthermore, all ICC values for RF

DISCUSSION

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in the older group were excellent, with both tone and stiffness >0.90 and elasticity 0.86, so reliability varied in specific situations. Interrater reliability for tone of BB was excellent in the younger participants (ICC 0.84) and good in older participants (0.67). Difficulties were encountered by the raters when locating the BB test site in older participants, as the muscle belly was less well defined and the muscle belly was not always centrally located on the upper arm, often falling medially. The attempt to standardise the test site by measuring the distance between anatomical landmarks may not have been as reliable as the more subjective method recommended in the MyotonPRO users’ manual, which instructs the user to identify the muscle belly by palpation during a slight contraction and visual inspection could be used during a slight contraction to locate the bulk of the muscle belly. The RF muscle on the other hand has more room for error and it would be helpful to quantify how far from the original testing site is permissible before inaccurate readings are obtained. Such a study is in progress in the authors’ laboratory.

While the present findings suggest that measuring tone, stiffness and elasticity in asymptomatic participants using the MyotonPRO is more reliable between raters for RF than for BB, and in younger than older males, further studies are needed in other asymmetrical groups, clinical populations and muscles, as well as in females. Previous literature on interrater reliability of earlier Myoton prototypes is of interest for comparison with the present findings. In a study of 20 adult females, 5 healthy and 15 with musculoskeletal disorders (mean age 44.2±14.7 years), reliability of measuring tone, stiffness and elasticity of the relaxed trapezius muscle was assessed using the Myoton-2 device (Viir et al. 2006). They found excellent ICC values for tone (0.99), stiffness (0.99) and elasticity (0.97) (Viir et al. 2006). Bizzini and Mannion carried out similar reliability testing using Myoton-2 in lower limb muscles: vastus lateralis (VL), rectus femoris (RF) biceps femoris (BF), lateral gastrocnemius (LG) and medial gastrocnemius (MG), in 10 healthy adult males and females (mean age 40±13 years); their focus was, however, on muscle stiffness (Bizzini and Mannion 2003). They equally recorded excellent interrater reliability for RF (0.84-0.85), BF (0.80-0.91), LG (0.86-0.93) and MG (0.80-0.88) but for VL, the ICCs ranged from poor to excellent (0.40-0.93).

Generally, the previous studies above reported excellent reliability for muscles assessed within the same session, using earlier Myoton prototypes. The MyotonPRO also showed excellent within session reliability for all three parameters and has the potential to be a useful tool for obtaining objective measurements of muscle tone, stiffness and elasticity. A key factor is to establish reliability of the operator between-days, as changes over time are used to monitor the effects of interventions. It is also necessary to know the amount of error in order to establish the degree of clinically important change. Intra-rater studies by the present group show acceptable reliability using the MyotonPRO, which vary for muscle and age (Aird et al. 2012; Bailey et al. 2013; Mooney et al. 2013; Mullic et al. 2012). Between-day reliability was better for quadriiceps than biceps brachii and in young than older participants.

### Absolute values for tone, stiffness and elasticity

Due to the small numbers of participants in the present study groups (n=21 young, n=21 older), the data for absolute values obtained by the same rater (Rater 1) are only used to indicate differences between muscles and age groups, which need to be confirmed in larger studies for statistical analysis. Muscle tone (frequency) varied little between participant groups and muscles studied. The range of tone values recorded for BB and RF in the healthy males were 14.29 (1.1) to 14.73 (0.8) Hz and 16.09 (1.2) to 16.36 (1.71) Hz respectively. Muscle stiffness, which is an indication of the muscle’s ability to resist changes of its shape caused by an external force, appeared to be greater in older than younger participants for RF but not for BB. The absolute values recorded for stiffness were greater in RF than BB (Table 1). Similar values to those in the present study for RF stiffness using the Myoton-2 in 10 young participants (5 females and 5 males, aged 40±13 years), with mean stiffness of 268 (±31) N/m in the right quadriiceps (Bizzini and Mannion 2003). In the current study, mean RF stiffness was 288 (±23) N/m and 322 (±28) for young and older males respectively. The large standard deviations in the data sets from the two studies, and the small participant numbers, indicate that these findings are similar between the two studies. Muscle values of logarithmic decrement were relatively higher in the older males (indicating lower elasticity) for both RF and BB. In both muscles elasticity appeared to be greater in the young than the older participants (RF 1.4±0.2 and 1.8 ±0.3; and BB 1.1 ±0.1 and 1.3 ±0.2). As mentioned above, larger studies are required to establish age related changes in these parameters.

### Limitations of the study

A limitation of the methodology that may have caused the lower reliability results in BB was the method of locating the testing site. Measuring multiple sites and ways of relocating them, particularly in older people, could be explored to determine the most reliable ways of locating the site for research purposes and clinical use. Muscle activity in the relaxed position was not assessed and instructing patients to relax and providing support for the limb in the testing position could have eliminated active contractions but does not rule this out as a potential confounding variable. This may be one of the reasons for variability in the measurements within or between raters and therefore could affect reliability. Future studies could use electromyography to objectively measure the state of the muscle rather than relying on participants to relax fully.

The number of participants was sufficient to examine reliability in (n=20) but too small to allow definitive conclusions to be drawn about differences in parameters between the RF and BB muscles or changes with ageing but the findings indicate that larger studies are warranted to establish reference data for the different groups and muscles.

### Potential clinical implications and future research

Further patient studies need to be conducted, particularly those presenting with neurological conditions, e.g. assessing tone in stroke (Chuang et al. 2012), Parkinson’s disease (Rätsep and Asser 2011), and compared with normative data to help inform clinical decision making. Also the device could be used as an evaluation tool in musculoskeletal and neurological conditions to assess muscle disease and injury and effects of rehabilitation.

### CONCLUSIONS

This present study confirms the interrater reliability of the MyotonPRO for objective assessment of skeletal muscle tone, stiffness and elasticity in the RF and BB muscles. The observed trend in absolute values forms the basis for larger studies to produce reference data and establish conclusive evidence of effects of ageing. Further research is needed to add to the existing literature to establish Myoton technology as a valid and reliable clinical research tool for examining the effects of injury, disease and interventions. Studies need to include various muscles in healthy groups with different levels of habitual physical and clinical populations, such as neurological and musculoskeletal conditions.

### Conflict of interest statement

None of the authors declare any potential conflict of interest.
There were no conflicts of interest within the present study, which was conducted independently of the company providing the equipment (Myoton Ltd, London).

**Key points**

1. Different raters obtained acceptably similar results in rectus femoris demonstrating the potential for MyotonPRO to be used for objective assessment of mechanical muscle properties.
2. Protocol for testing biceps brachii in older participants could be modified to improve reliability.
3. The MyotonPRO device could be used as an evaluation tool in musculoskeletal and neurological conditions to assess muscle disease and injury and effects of rehabilitation.
4. The observed trend in absolute values forms the basis for larger studies to produce reference data and establish conclusive evidence of effects of ageing.

**References**


