Reproducible Measurements of Muscle Characteristics Using the MyotonPRO Device: Comparison Between Individuals With and Without Paratonia

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ABSTRACT

Background and purpose: The MyotonPRO is a portable device that measures muscle tone and biomechanical muscle properties objectively. MyotonPRO has already proven to be effective in measuring muscle properties in healthy and diseased populations. However, to the best of our knowledge, it has never been tested in individuals suffering from paratonia, a form of hypertonia frequently accompanying dementia. The aims of the present study were to (1) compare muscle tone, elasticity, and stiffness between 3 different subpopulations of young and old healthy adults and individuals with paratonia, and (2) investigate the intra- and interrater reproducibility of MyotonPRO measurements of the biceps brachii (BB) muscle in each subpopulation.

Methods: MyotonPRO measurements of muscle tone, elasticity, and dynamic stiffness were carried out by 2 investigators on 2 different days over the BB muscles of 54 participants (18 healthy young adults, 20 healthy older adults, and 16 older individuals with paratonia). Muscle properties were compared between subpopulations using ANOVA/Welch and post hoc tests. Reliability (intraclass correlation coefficient) and agreement parameters (standard error of measurement and the minimal detectable change) were calculated.

Results: Statistically significant differences between subpopulations were found in all parameters, except for stiffness between healthy elderly and individuals with paratonia. In the healthy subpopulations, (a) intrarater reliability was very high and intrarater agreement was good between 2 consecutive series, (b) between days intrarater reliability was low to high and intrarater agreement was variable, (c) interrater reliability was high to very high and interrater agreement was good. In individuals with paratonia, (a) intrarater reliability was moderate to high and agreement was variable between series, (b) between days intrarater reliability was poor to moderate and agreement was poor, (c) interrater reliability ranged from low to high with poor agreement.

Conclusions: MyotonPRO measurements of the BB muscle showed good reproducibility in both healthy subpopulations, particularly for measurements performed within the same day. In individuals with paratonia, reliability and agreement were substantially lower. MyotonPRO can be used in clinical assessment and research. However, in individuals with paratonia, careful interpretation of results is required. Research in a larger sample of persons with paratonia at different stages of disease severity is recommended.

Key Words: dementia, muscle tone, MyotonPRO, paratonia, reproducibility

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INTRODUCTION

Muscle tone can be defined as the continuous resting tension or the resistance in response to stretching. It is an essential feature of a healthy and well-functioning muscle, which enables the production of effective and efficient movement of our limbs and provides an appropriate position of the body at rest as well as in action.[1] Consequently, inappropriate muscle tone impedes adequate movement and posture.[2] In several pathological conditions, such as stroke and cerebral palsy, muscle tone is affected. As a result, proper assessment of muscle tone is crucial from a clinical perspective in a wide range of rehabilitation domains, to aid in management of disease progression and evaluate the effect of therapeutic interventions. Currently, clinical estimation of muscle tone is commonly performed using the Modified Ashworth Scale[3] (MAS) or by manual palpation. Despite the usefulness of these tools in daily clinical practice to grade major subcategories of muscle

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tone, the precision to find subtle changes in muscle properties, which is indispensable in research, is lacking.

Although muscle tone is commonly defined as the central mediated resistance to passive movement, peripheral components such as changes in biomechanical muscle properties (such as elasticity and stiffness) may also play an important role.[1,4] Recently, a noninvasive device known as the MyotonPRO, which combines the assessment of peripheral biomechanical muscle properties with muscle tone in 1 single measurement, was introduced. Studies in healthy participants as well as in individuals with stroke or Parkinson's disease have shown a moderate to very high reliability of the MyotonPRO for measuring muscle properties.[5-10] Importantly, however, biomechanical muscle properties can be characteristically different in each neurological condition. Therefore, the reliability of these measurements may vary between patient populations. Hence, these previous findings, from diverse neurological conditions, cannot necessarily be generalized from one patient group to another.

To date, the MyotonPRO device has been tested in patients with Parkinson's disease[8] and stroke[9,11] but, to the best of our knowledge, not yet in patients suffering from paratonia. According to Hobbelen et al, paratonia is a form of hypertonia with an involuntary variable resistance during passive movement. The degree of resistance varies depending on the speed of movement and is proportional to the amount of force applied. The resistance to passive movement is in any direction and there is no clasp-knife phenomenon. Moreover, paratonia increases with progression of dementia.[12] Although the presence of paratonia can have an enormous impact on daily care and comfortable positioning especially in the more advanced stages,[13] reliable evidence-based interventions in this population are challenging.[14] To comply with clinical guidelines, the effects of any intervention should be assessed in perspective of the levels of the International Classification of Functioning, Disability, and Health model. The levels of activities and participation of this model are essential in individuals with paratonia. However, as paratonia frequently accompanies dementia, self-reporting and understanding of guidelines and commands of any testing are hampered for validity, reliability, and meaningfulness, due to the cognitive deterioration in these patients. For this reason, an objective technical metric assessment at the level of impairment (eg, muscle tone), without the requirement of understanding commands, could significantly improve the evaluation and therapeutic contribution of an intervention.

In addition, despite the valuable research into the psychometric properties that was conducted, some important gaps still remain. First of all, most intrarater reliability studies focused on test-retest reliability within the same day.[5-9,11] However, for the assessment of an intervention effect or process, between-day reliability should not be neglected. Second, reliability does not necessarily represent the total aspect of reproducibility. According to de Vet et al,[15] reproducibility can be described both by agreement and by reliability parameters, according to the question that should be answered. Agreement parameters assess how close the results of the repeated measurements are, by estimating the measurement error in repeated measurements, whereas reliability parameters assess whether participants can be distinguished from each other, despite measurement errors.[15]

Besides the effect of aging, we hypothesize that paratonia will have an influence on muscle tone and biomechanical properties measured by MyotonPRO. Therefore, the aims of the present study were to (1) compare muscle tone, elasticity, and stiffness between 3 different subpopulations of young and old healthy adults and individuals with paratonia, and (2) investigate the intra- and interrater reproducibility of MyotonPRO measurements of the biceps brachii (BB) muscle in each subpopulation.

METHODS

Participants

To enlarge the contrast between individuals with and without paratonia, we targeted 3 different subpopulations (purposive sampling): (1) healthy young adults (n = 18), (2) healthy older adults (n = 20), and (3) older adults with dementia and paratonia (n = 16). For the healthy adults, the exclusion criteria were presence of any neurological disease and/or usage of medication with impact on muscle tone. They were recruited using an informative leaflet, distributed both among staff of the department of Rehabilitation Sciences and Physiotherapy of the Ghent University, and in a senior's leisure club in Ghent. The individuals with paratonia were recruited from 2 nursing homes. All of them had a diagnosis of dementia, and presence of paratonia was evaluated with the Paratonia Assessment Instrument. The Paratonia Assessment Instrument is a diagnostic tool for paratonia, in which the 4 limbs of the participant are moved passively, both slowly and rapidly; the presence of paratonia is estimated by criteria based on the consensus definition.[16] Medication usage and neurological comorbidities were recorded. The study was approved by the Ethical Committee of the Ghent University Hospital, and all participants (or legal representative) signed an informed consent.

Device

The MyotonPRO is a small, noninvasive hand-held apparatus that provides objective measurements of mechanical muscle properties expressed on a continuous scale. After the device probe is positioned on the skin surface above the muscle being measured, and thereby slightly compressing subcutaneous superficial tissue, it exerts a light quick-released mechanical impulse. The subsequent dampened oscillation of the muscle is recorded by an accelerometer and numeric values of muscle parameters are calculated, representing the muscle tone, and biomechanical properties (http://www.myoton.com/en/Technology). *F [Oscillation Frequency (Hz)]* indicates the state of intrinsic tension or muscle tone in a passive resting state, without any voluntary contraction. The higher the oscillation frequency, the higher the muscle tone. Frequency increases with contraction or muscle stretch. *D [Logarithmic Decrement of the muscle's natural oscillation]* represents the muscle's elasticity, indicating how much mechanical energy dissipates into the muscle tissue during a single oscillation cycle. Elasticity is inversely proportional to the decrement (the smaller the value of D, the higher the muscle's elasticity). It quantifies the muscle's ability to recover its initial shape after removal of the external force. *S [Dynamic Stiffness (N/m)]* is a biomechanical muscle property that depicts the resistance to contraction from an external force trying to deform its initial shape. Myotonometric measurement of muscle tone, elasticity, and stiffness has been described as reliable, valid, and responsive outcome measures for muscle property assessment in stroke rehabilitation.[11] In individuals with Parkinson's disease, a significant correlation has been found between myotonometric measurement of BB muscle belly stiffness and clinical rating of parkinsonian rigidity.[8]

Procedure

MyotonPRO measurements were performed in supine position, elbows flexed in 90° with hands supported on the abdomen (Figure 1). This position was chosen to avoid discomfort in the individuals with paratonia because their full range of motion during elbow extension was not always feasible, and this could thereby affect the muscle tone measurements.

Figure 1. Illustration of measurements with the MyotonPRO device.

The measuring point was determined centrally on the BB muscle belly, at about one-third of the total muscle length (starting distally). The measuring point was marked and the distance to the cubital fossa was registered to locate a reproducible site over the muscle belly in both testing sessions. The used measurement mode was multiscan (10 taps) with a tap time of 15 milliseconds and 2 consecutive series of 10 taps were conducted. If the coefficient of variation (CV) in a series of 10 taps was 3% or more, the measurement was repeated until all CV values were less than 3%, as recommended in the MyotonPRO user's manual.

On each day, measurements were performed on both left and right BB muscles by 2 raters subsequently. The raters had little experience with the device (1 training session), and the measurements were performed independently but using the same measurement point. The retesting took place on the same day of the following week. Participant characteristics–age, length, and weight—were recorded if available. In individuals with paratonia, muscle tone of the left and right elbow flexor and extensor muscles was estimated using the MAS. The sum of these 4 MAS scores (MAS sum) provides a global view of the severity of paratonia in each individual.[14,17,18]

Statistical Analysis

MyotonPRO data were imported and analyzed using Statistical Package for the Social Sciences version 22 (SPSS 22). The data were checked for normality using the Shapiro-Wilks test.

To compare muscle properties of the different subpopulations, analysis of variance (ANOVA)/Welch and post hoc tests were performed and boxplots were used to display data graphically. Intrarater reliability (between series and between days) and interrater reliability were analyzed through the intraclass correlation coefficient (ICC), using a 2-way mixed model with absolute agreement and single measures ICC.

To determine the most appropriate number of taps needed for an objective measurement, interrater reliability and intrarater reliability between days were calculated twice: first using the mean of 2 series (mean of 20 taps), and second using the mean of only the first series (mean of 10 taps). For interpretation of the ICC values, the criteria of Domholdt were used: 0.90 or more = very high, 0.89 to 0.7 = high, 0.69 to 0.5 = moderate, 0.49 to 0.26 = low, and 0.25 or less = poor.[19] For the agreement estimation, standard error of measurement (SEM) was calculated as $SEM = SD \times \sqrt{(1 - ICC)}$, where SD is standard deviation for all observations for the parameter concerned in the given subpopulation. SEM% represents the relative amount of measurement error and is calculated as $SEM\% = (SEM/mean) \times 100$. In this formula, "mean" indicates the mean of all measurements for the corresponding parameter for each subpopulation. SEM% of less than 10% was arbitrarily considered to be small.[20] To estimate the clinical relevance, the minimal detectable change (MDC) was calculated. MDC is the minimum difference between 2 measurements that is necessary to indicate 95% confidence of a real difference between the true scores of a single individual, and is defined by MDC = 1.96 × SEM × √2.[21] MDC% is calculated as MDC% = (MDC/mean) × 100. MDC% interpretation is arbitrary, although Chuang et al[9] suggested that MDC% smaller than 10% can be considered excellent, and MDC% smaller than 30% can be considered acceptable. For all reproducibility analysis data from left biceps were used, for intrarater between series and interrater reproducibility data from day 1 were used, and for intrarater reproducibility data from rater 1 were used. These were chronologically the first conditions in the test procedure and thereby not affected by previous measurements. Moreover, by using the data of the left arm (this was mostly the nondominant arm in the healthy subpopulations; in the individuals with paratonia dominance was unknown), we tried to reduce the influence of foregoing physical activity. For all analyses, a significance threshold was set at $P < .01$.

RESULTS

Participants

In total, 54 persons participated in this study: 18 healthy young adults (mean age 28.4 years), 20 healthy older adults (mean age 79.6 years), and 16 older adults with paratonia (mean age 85.5 years). Participant characteristics are presented in Table 1. In individuals with paratonia, the presence of neurological comorbidities and medication usage were recorded. From this subpopulation, 3 participants had a history of stroke or transient ischemic attack, and 6 of them used medication with possible influence on muscle tone. Influence of medication and/or neurological comorbidities on muscle parameters was assessed without yielding significant effects.

Muscle Tone and Mechanical Properties

Parameter characteristics and variance analysis statistics are displayed in Table 2. For all parameters ANOVA/Welch revealed statistically significant differences ($P < .001$) between the 3 subpopulations. Post hoc tests were all significant ($P < .001$), except for muscle dynamic stiffness between healthy older adults and individuals with paratonia ($P = .986$). Subpopulation differences are graphically displayed in Figure 2.

Intrarater Reproducibility Between Series

Intrarater reliability and agreement between series are displayed in Table 3. Intrarater reliability between the consecutive series was very high in healthy young and older adults and moderate to high in individuals with paratonia.

In the healthy subpopulations, intrarater agreement between series was good; all SEM% were less than 10%, and MDC% varied from excellent (<10%) to acceptable (<30%), whereas in individuals with paratonia SEM% exceeded 10% for muscle tone and for stiffness and all MDC% exceeded 10% or even 30%.

Intrarater Reproducibility Between Days

Intrarater reproducibility between days is represented in Table 4. Reliability ranged from moderate to high in healthy young adults, and from low to moderate in healthy older adults, regardless of the amount of series used. In individuals with paratonia, intrarater reliability between days ranged from poor to moderate when using only 1 series (10 taps), and from poor to low when using 2 series of taps (20 taps).

Intrarater agreement between days differed between the subpopulations. In healthy young adults, all SEM% were less than 10%, and MDC% ranged from acceptable (<30%) to excellent (<10%). In healthy older adults only for muscle tone, SEM% was less than 10% and MDC% less than 30%. In individuals with paratonia, all SEM% exceeded 10% and all MDC% exceeded 30%.

Interrater Reproducibility

In Table 5, interrater reproducibility is presented. In healthy young adults, interrater reliability was high; in healthy older adults, interrater reliability ranged from high to very high. In individuals with paratonia, interrater reliability ranged from low to high when 2 series were used, and from low to moderate when only 1 series was used.

In healthy young and older adults, all SEM% were less than 10% and MDC% were less than 30%. In individuals with paratonia, all SEM% values exceeded 10% and all MDC% exceeded the benchmark of 30%.

Table 1. Mean, Standard Deviation, and Range of Participant Characteristics by Subpopulation

	Young Adults (n = 18) (4 Male/14 Female)		Older Adults (n = 20) (7 Male/13 Female)		Individuals With Paratonia (n = 16) (3 Male/13 Female)	
Participant Characteristics	Mean (SD)	Range	Mean (SD)	Range	Mean (SD)	Range
Age, y	28.4 (3.5)	24-34	79.6 (5.6)	66-87	85.5 (6.8)	70-98
Length, cm	170.4 (9.1)	155-192	163 (8.8)	150-180	N/A (N/A)	N/A
Weight, kg	63.5 (8.5)	48-80	68.1 (10.6)	50-85	N/A (N/A)	N/A
BMI, kg/m^2	21.8 (1.9)	18.7-25.8	25.3 (3.0)	19.1-31.2	N/A (N/A)	N/A
MAS sum	N/A (N/A)	N/A	N/A (N/A)	N/A	10.9 (3.2)	6-16

Abbreviations: BMI, body mass index; MAS, Modified Ashworth Scale; N/A, information not available; SD, standard deviation.

Table 2. Parameter Characteristics, ANOVA/Welch and Post Hoc Test of Tone, Elasticity, and Stiffness of the Biceps Brachii Muscle of Healthy Young and Older Adults and Individuals With Paratonia

Parameter Characteristics	Young Adults	Older Adults	Individuals With Paratonia
Tone, Hz			
Mean (SD)	11.80 (0.84)	14.02 (1.83)	15.01 (2.81)
Range (min-max)	4.47 (10.34-14.81)	15.29 (10.50-25.79)	19.98 (10.51-30.49)
ANOVA/Welch		$P < .001$	
Tukey post hoc			
Young adults	/	$P < .001$	$P < .001$
Older adults	$P < .001$	/	$P < .001$
Individuals with paratonia	$P < .001$	$P < .001$	/
Elasticity (log decrement)			
Mean (SD)	1.47 (0.19)	1.84 (0.37)	1.71 (0.43)
Range (min-max)	0.99 (1.05-2.05)	1.82 (1.00-2.82)	2.15 (0.90-3.05)
ANOVA/Welch		$P < .001$	
Tukey post hoc			
Young adults	/	$P < .001$	$P < .001$
Older adults	$P < .001$	/	$P < .001$
Individuals with paratonia	$P < .001$	$P < .001$	/
Stiffness, N/m			
Mean (SD)	199.84 (20.14)	273.89 (53.03)	273.20 (70.86)
Range (min-max)	91.80 (148.70-240.50)	533.80 (166.80-700.60)	510.3 (129.90-640.20)
ANOVA/Welch		$P < .001$	
Tukey post hoc			
Young adults	/	$P < .001$	$P < .001$
Older adults	$P < .001$	/	$P = .986$
Individuals with paratonia	$P < .001$	$P = .986$	/

Abbreviations: ANOVA, analysis of variance; SD, standard deviation.

DISCUSSION

Muscle Tone and Mechanical Properties

Muscle tone is commonly defined as the resistance of the muscle to passive movement and therefore traditionally assessed in a dynamic way (ie, movement of the limb). Although MyotonPRO measurements may seem static, the small mechanical impulse exerted by the MyotonPRO probe evokes a small, local passive movement of muscle tissue, which is effectively captured by this device. In the present study, MyotonPRO was able to detect a significantly higher muscle tone in individuals with paratonia than in healthy adults. Furthermore, besides a higher mean, the range of the measured muscle tone values (Table 2) was also higher in the paratonia subpopulation. Regarding the other muscle parameters, elasticity was significantly lower and stiffness significantly higher in individuals with paratonia than in the healthy young adult subpopulation. Surprisingly, however, compared with healthy older adults, elasticity was higher and stiffness was lower in individuals with paratonia. These findings are remarkable and unexpected, because peripheral biomechanical changes have been hypothesized to contribute in the development of increased muscle tone, which is typically seen in individuals with paratonia.[4,22-24] Based on this, finding a plausible explanation for these findings seems dubious. However, we speculate that our results could be partially explained by our inability to differentiate between different stages of disease severity in our sample size of individuals with paratonia. Hence, further research is planned to be conducted, and besides increasing the sample size and differentiating between the stages of dementia and paratonia to confirm and refine our observations, other elements such as individual anatomy of amount and thickness of fat tissue underneath the skin and/or differences in sarcomere length will also be considered. For instance, individuals with paratonia are often skinnier than their healthy peers. This is why the thickness of subcutis and the amount of subcutaneous fat need to be taken into account. In addition, the total elbow range of motion differed between healthy adults and individuals with paratonia, which could potentially lead to differences in sarcomere length at 90°of flexion and thereby possibly affecting titin properties and immunoglobulin

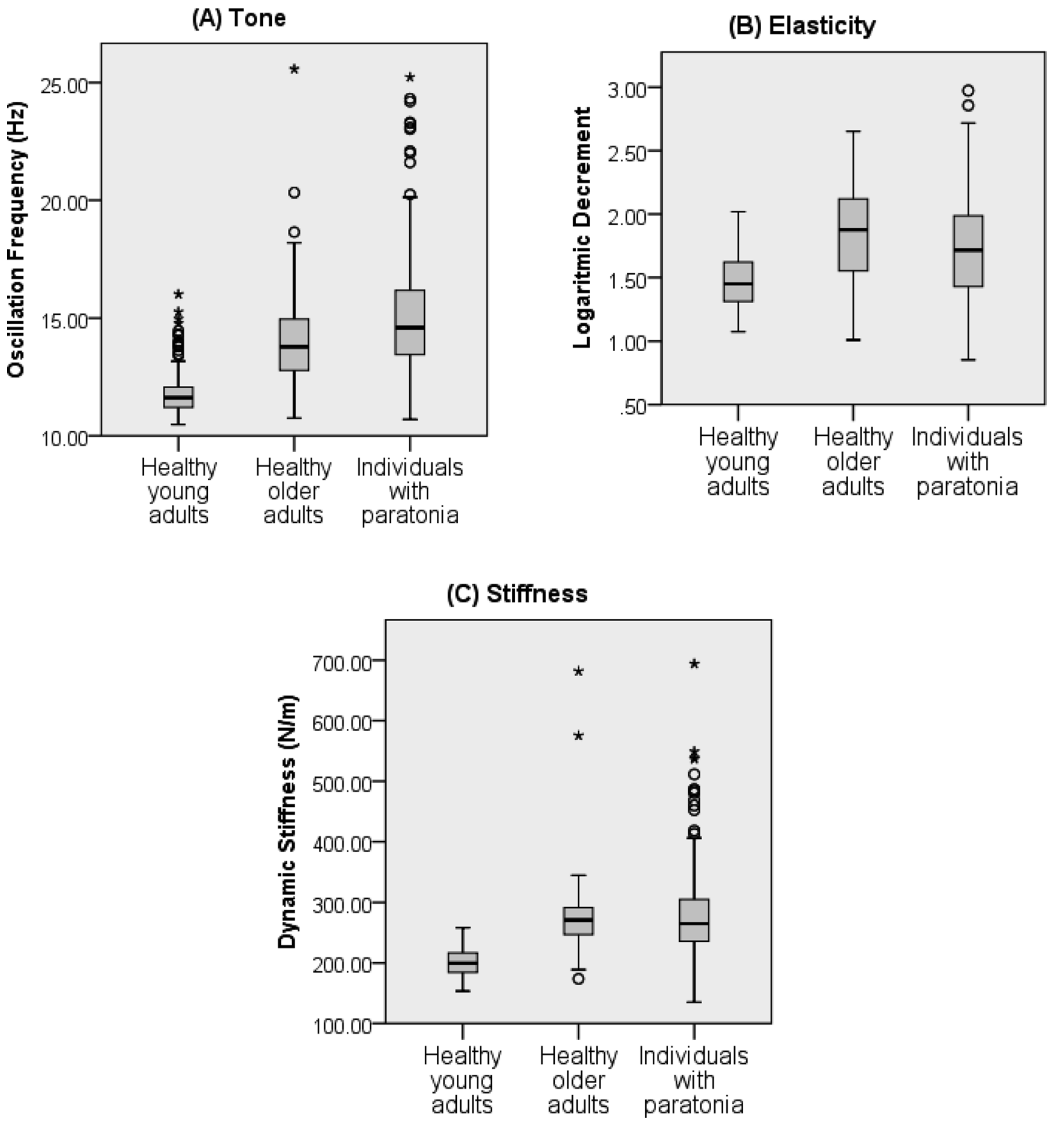

Figure 2. Boxplot visualization of (A) tone, (B) elasticity, and (C) stiffness of biceps brachii muscle between healthy young adults, healthy older adults, and individuals with paratonia.

domain refolding. However, further fundamental research is needed to clarify this hypothesis.

When comparing healthy older adults with healthy young adults, higher muscle tone, lower elasticity, and higher stiffness as well as a broader range in each of these parameters can be observed in the older subpopulation. Potentially, structural changes in the individual aging muscles may be responsible for these findings.[25-28]

Compared with previous studies in healthy adults using MyotonPRO, our values of muscle tone were lower, while elasticity and stiffness were higher.[5-7] A possible explanation for this deviating findings might be the difference in elbow flexion angle (and thereby different elongation of the BB muscle) in the supine position. To avoid discomfort in individuals with paratonia, all our participants were tested in 90°, versus 10° to 15° in previous studies.[5-7] The influence of elbow angle on MyotonPRO results remains however unclear and should be investigated in future studies.

Intrarater Reproducibility Between Series

Intrarater reliability between series was very high for all parameters in the healthy subpopulations, which is in accordance with previous studies.[5-7,10] ICC values were remarkably lower in individuals with paratonia (Table 3). We argue this might be due to the susceptibility of individuals with paratonia for external influences. For example, a sudden noise during one of the series of taps might remain unnoticed by the rater but can affect muscle tone in individuals with paratonia. Also, due to the muscle tone fluctuations in individuals with paratonia, it was often necessary to repeat several testing series to obtain a CV less than 3% (as recommended in the MyotonPRO user's manual).

Table 3. Intrarater Reproducibility Between Series[a]

Intrarater Reproducibility Between Series	Healthy Young Adults	Healthy Older Adults	Individuals With Paratonia
Tone, Hz			
ICC (95% CI)	0.971 (0.925-0.989)	0.942 (0.858-0.977)	0.571 (0.131-0.829)
SEM	0.14	0.44	1.84
SEM%	1.21	3.14	12.26
MDC	0.40	1.22	5.10
MDC%	3.36	8.71	33.99
Elasticity (log decrement)			
ICC (95% CI)	0.952 (0.877-0.982)	0.966 (0.895-0.988)	0.875 (0.672-0.956)
SEM	0.04	0.07	0.15
SEM%	2.83	3.71	8.89
MDC	0.12	0.19	0.42
MDC%	7.85	10.28	24.64
Stiffness, N/m			
ICC (95% CI)	0.98 (0.947-0.992)	0.94 (0.670-0.982)	0.797 (0.397-0.933)
SEM	2.85	12.99	31.93
SEM%	1.43	4.74	11.69
MDC	7.89	36.01	88.50
MDC%	3.95	13.15	32.39

Abbreviations: CI, confidence interval; ICC, intraclass correlation coefficient; MDC, minimal detectable change; SEM, standard error of measurement.
[a]ICC, 95% confidence interval of ICC, SEM (%) and MDC (%) for tone, elasticity, and stiffness of the biceps brachii muscle of healthy young and older adults and individuals with paratonia.

The best agreement was found in healthy young adults, with small SEM% and excellent MDC%.[9,20] In healthy older adults, SEM and MDC values were slightly higher than in healthy young adults, nevertheless SEM% were small and MDC% were acceptable to excellent.[9,20] In individuals with paratonia, SEM and MDC values were higher than in the healthy subpopulations, indicating lower agreement; for muscle tone and stiffness, SEM% exceeded 10% and MDC% exceeded 30%. The SEM and MDC values of the healthy subpopulations in the present study are somewhat higher than the values reported in previous studies.[6,7,10] Possibly this difference may be caused by participant characteristics. In the previous studies all participants were males.[6,7,10] However, a possible gender relationship is not investigated yet.

Intrarater Reproducibility Between Days

Also for intrarater reliability between days, differences were found between the subpopulations (Table 4). The highest reliability (ie, moderate to high) was found in healthy young adults. Again, the lowest reliability (poor to moderate) was found in individuals with paratonia. In the present study, for all parameters intrarater between-day reliability was substantially higher in healthy young adults than in healthy older adults. In a previous study, this could only be established for muscle tone and stiffness but not for elasticity.[10]

In healthy young adults, all intrarater between-day SEM% were less than 10% and MDC% were less than 30%; this indicates that small changes within a group of individuals could be effectively detected using the MyotonPRO.[9,20] In healthy older adults, only for muscle tone SEM% less than 10% and MDC% less than 30% were obtained. The higher agreement for healthy young adults compared with older adults is in line with findings of Agyapong-Badu et al.[10] In individuals with paratonia, all SEM% and MDC% exceeded largely the proposed thresholds. This might suggest this device would—in the given protocol—be less suitable to detect small changes over time. On the other hand, up to now there is no valuable alternative device that provides this specific information. Besides, the fluctuating nature of paratonia is a real challenge for any assessment tool. Moreover, we consider that appropriate consideration of additional outcome parameters such as pain and difficulties in daily care could provide further insight into the effects of an intervention for paratonia.

Obviously, intrarater reproducibility between days is lower than intrarater reproducibility between series (ie, within the same day). That is not surprising, because when comparing measurements from 2 different days, more factors such as fluctuations in measurement circumstances (eg, room temperature and background noise) and muscle conditions of the participants (eg, related to physical activity previous to the testing moment, mood changes, and exact timing of medication intake) could have affected our results. The described reproducibility should be interpreted as a combination of reproducibility of the device

Table 4. Intrarater reproducibility Between Days[a]

Intrarater Reproducibility Between Days	Using Mean of 2 Series (20 Taps)			Using Only First Series (10 Taps)		
	Healthy Young Adults	Healthy Older Adults	Individuals With Paratonia	Healthy Young Adults	Healthy Older Adults	Individuals With Paratonia
Tone, Hz						
ICC (95% CI)	0.894 (0.733 to 0.960)	0.591 (0.193 to 0.821)	0.229 (−0.310 to 0.653)	0.871 (0.679 to 0.951)	0.618 (0.214 to 0.837)	0.511 (−0.004 to 0.807)
SEM	0.27	1.17	2.47	0.30	1.13	1.96
SEM%	2.32	8.35	16.44	2.56	8.07	13.09
MDC	0.76	3.24	6.84	0.84	3.14	5.45
MDC%	6.42	23.14	45.56	7.09	22.36	36.29
Elasticity (log decrement)						
ICC (95% CI)	0.646 (0.244 to 0.857)	0.369 (−0.105 to 0.701)	0.348 (−0.197 to 0.723)	0.565 (0.118 to 0.818)	0.365 (−0.096 to 0.696)	0.192 (−0.371 to 0.637)
SEM	0.11	0.29	0.35	0.13	0.29	0.39
SEM%	7.69	15.97	20.30	8.52	16.02	22.60
MDC	0.31	0.81	0.96	0.35	0.82	1.07
MDC%	21.32	44.28	56.28	23.63	44.42	62.65
Stiffness, N/m						
ICC (95% CI)	0.845 (0.615 to 0.941)	0.397 (−0.045 to 0.712)	0.465 (−0.044 to 0.782)	0.795 (0.529 to 0.920)	0.477 (0.047 to 0.759)	0.317 (−0.244 to 0.708)
SEM	7.93	41.18	51.83	9.12	38.35	58.56
SEM%	3.97	15.04	18.97	4.56	14.00	21.44
MDC	21.98	114.14	143.66	25.28	106.30	162.32
MDC%	11.00	41.67	52.59	12.65	38.81	59.42

Abbreviations: CI, confidence interval; ICC, intraclass correlation coefficient; MDC, minimal detectable change; SEM, standard error of measurement.
[a]ICC, 95% CI of ICC, SEM (%), and MDC (%) for tone, elasticity, and stiffness of the biceps brachii muscle of healthy young and older adults and individuals with paratonia.

(measuring a muscle in exactly the same condition on both occasions) and the variability in muscle condition. Notwithstanding our efforts, this variability could not be completely excluded, which may have been of importance especially for persons with paratonia. Apart from that, our method of (re)locating the point of measurement might have also added more variability in our between-day results, especially in older individuals. More specifically, the muscle belly of older adults is often less voluminous, and the location of the middle of the BB muscle belly might be situated some more medially and distally.[5,6] This is why our methodology focused on the proximodistal distance and determined the exact mediolateral testing site by subjectively palpating the muscle belly. Only the proximodistal distance was recorded, and as a result, this could have added some (mediolateral) variation when retracing the location of the measurement in the retest.

Interrater Reproducibility

In the present study, for all 3 parameters, interrater reliability was the highest in healthy older adults. Agyapong-Badu et al[5] described this tendency only for elasticity whereas for muscle tone and stiffness the highest ICC values were reported in young adults.

Interrater reliability ranged from high to very high in the healthy subpopulations (Table 5), whereas in individuals with paratonia interrater reliability ranged from low (muscle tone) to moderate (elasticity and stiffness) when 1 series of taps was used, and from low (muscle tone) to moderate (elasticity) and high (stiffness) when 2 series of taps were used. A plausible assumption for the lower interrater reliability in individuals with paratonia compared with the healthy subpopulations is again the variable and sensitive nature of paratonia, enhancing possible variability within subsequent measurements.

The best interrater agreement was found in healthy young adults, with SEM% less than 10% and MDC% less than 30%. This better agreement in healthy young adults compared with older adults for all parameters is in line with a previous study.[5] Although all SEM(%) and MDC(%) values were higher in older than in younger adults, still nearly all SEM% of healthy older adults were less than 10% and MDC% were less than 30%. In individuals with paratonia, all SEM% exceeded 10% and all MDC% exceeded 30%.

Notably, in the present study the reliability and agreement show different tendencies when comparing the 2 healthy subpopulations; although reliability was higher in

Table 5. Interrater Reproducibility[a]

Interrater Reproducibility	Using Mean of 2 Series (20 Taps)			Using Only First Series (10 Taps)		
	Healthy Young Adults	Healthy Older Adults	Individuals With Paratonia	Healthy Young Adults	Healthy Older Adults	Individuals With Paratonia
Tone, Hz						
ICC (95% CI)	0.753 (0.257 to 0.914)	0.783 (−0.023 to 0.941)	0.426 (−0.101 to 0.763)	0.761 (0.256 to 0.918)	0.777 (0.145 to 0.929)	0.494 (0.001 to 2.920)
SEM	0.42	0.85	2.13	0.41	0.86	2.00
SEM%	3.54	6.08	14.18	3.48	6.16	13.32
MDC	1.16	2.36	5.90	1.14	2.40	5.54
MDC%	9.81	16.85	39.31	9.65	17.09	36.91
Elasticity (log decrement)						
ICC (95% CI)	0.878 (0.197 to 0.968)	0.9 (0.766 to 0.959)	0.623 (0.177 to 0.856)	0.836 (0.247 to 0.951)	0.895 (0.755 to 0.957)	0.53 (0.024 to 0.815)
SEM	0.07	0.12	0.26	0.08	0.12	0.29
SEM%	4.51	6.36	15.44	5.23	6.52	17.24
MDC	0.18	0.32	0.73	0.21	0.33	0.82
MDC%	12.51	17.63	42.80	14.51	18.06	47.79
Stiffness, N/m						
ICC (95% CI)	0.842 (0.013 to 0.961)	0.904 (0.558 to 0.970)	0.731 (0.369 to 0.901)	0.815 (0.029 to 0.951)	0.9 (0.740 to 0.961)	0.648 (0.219 to 0.867)
SEM	8.01	16.43	36.75	8.66	16.77	42.04
SEM%	4.01	6.00	13.45	4.33	6.12	15.39
MDC	22.19	45.54	101.87	24.01	46.48	116.53
MDC%	11.10	16.63	37.29	12.02	16.97	42.65

Abbreviations: CI, confidence interval; ICC, intraclass correlation coefficient; MDC, minimal detectable change; SEM, standard error of measurement.
[a]ICC, 95% CI of ICC, SEM (%), and MDC (%) for tone, elasticity, and stiffness of the biceps brachii muscle of healthy young and older adults and individuals with paratonia.

the oldest, agreement was higher in the youngest individuals. This finding supports the importance of investigating both aspects of reproducibility and highlights the strength and novelty of our study design. On one hand, reliability is about distinguishing individuals from each other despite measurement errors and therefore will be facilitated if variability between individuals is high, which is frequently the case in older adults. On the other hand, for agreement between repeated measures, measurement error is more determinant. It is possible that in our results, this measurement error was increased in the older adult subpopulation due to body composition characteristics of our participants. For example, lower muscle mass due to aging, high body mass index, and/or high subcutaneous fat percentage could impede appropriate muscle palpation and thereby jeopardize precise localization of the measuring point and increase measurement errors in the collection data.

Number of Series Used

In our study design, we included 2 different protocols to calculate intrarater between days (Table 4) and interrater reproducibility (Table 5). This was done purposefully to determine the most appropriate number of taps needed for an objective measurement without compromising the time-effectiveness of this assessment. In previous studies the amount of taps was very diverse. Aird et al[29] found higher reliability and agreement in MyotonPRO measurements of quadriceps muscles of older males when using the mean of 2 series of 10 taps than using only 1 series.

In this study we performed 2 series of 10 taps and reproducibility was calculated both using 1 and 2 series. When comparing the results, we found interesting dissimilarities between the subpopulations. In general, in all subpopulations reproducibility was higher when the mean of 2 series was used. However, the increase in reproducibility by adding a second series was higher in individuals with paratonia than in healthy adults. When performing MyotonPRO measurements in healthy participants therefore, one should consider whether it is worth the effort of performing a second series to increase reproducibility. On the other hand, in individuals with paratonia, the added value of this additional series is apparent. This finding could provide additional guidelines to improve experimental designs of studies using MyotonPRO.

Study Limitations

Apart from the difficulties in standardizing the exact location of the measuring point on the BB muscle, some other limitations of the present study should be taken into account. First, important variables that could influence muscle tone, stiffness, and elasticity, such as ambient and body temperature, blood flow, alcohol consumption, and the degree of foregoing physical activity levels, were not controlled for. Second, for the individuals with paratonia, information about length, weight, and body mass index was not available even though we assume body composition may impact our assessments. Third, it should also be mentioned that although all participants were very collaborative, keeping still during the tests was not straightforward. This was particularly the case in individuals with paratonia, especially because the measurements had to be repeated if not comply with a CV less than 3%, which was often challenging. Furthermore, because of practical reasons, the measurements in individuals with paratonia were performed in the nursing homes. As a consequence it was hard to control for environmental factors (eg, background noise) which are possibly influencing muscle tone in this patient group. Finally, future studies should examine validity in this subpopulation.

CONCLUSIONS

The results from this study show a good reproducibility of the MyotonPRO measurements of the BB muscle in our healthy subpopulations, particularly for measurements within the same day. However, in individuals with paratonia, both reliability and agreement are fairly lower. Hence, the MyotonPRO can be used in clinical assessment and research as an objective and more precise alternative for rough subjective scales, although in individuals with known changes in muscle tone one should elaborate a precise methodology and careful interpretation of results. Further research in a larger sample of individuals with paratonia at different stages of severity is recommended.

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