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Myotonometry as a measure to detect myofascial trigger points: an inter-rater reliability study

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Abstract

Objective: Several diagnostic methods have been used in the identification of mechanical properties of skeletal muscle, including myofascial trigger points (MTrPs), however, they are not suitable for daily clinical use. Myotonometry offers an easy noninvasive alternative to assess these muscle properties. Nevertheless, previous research has not yet studied the mechanical properties of MTrPs by myotonometry. The purposes of this study were (1) to analyze the differences in the mechanical properties between latent MTrPs and their taut bands by myotonometry, (2) to investigate the inter-rater reproducibility of myotonometric measurements, and (3) to examine the association between myotonometry and passive isokinetic dynamometry. *Approach*: Fifty individuals (58% male; age 24.6 $\pm$ 7.9 years) with a latent medial MTrP of the right soleus muscle participated. The mechanical properties of this MTrP area of soleus muscle and its taut band area were measured using a myotonometer (MyotonPRO). Additionally, passive resistive torque and extensibility of triceps surae muscle were assessed using a Kin-Com dynamometer. *Main results*: Statistical analysis indicated higher values for the stiffness parameter in the taut band with respect to the MTrP ($P < 0.05$). The inter-rater reliability of the myotonometric measurements was good for all variables ($ICC_{3,1} > 0.75$). The standard error of measurement (SEM) and minimal detectable difference (MDD) indicated a small measurement error for frequency and stiffness variables (SEM% $< 10\%$; $MDD_{95\%} < 20\%$). Significant fair correlations between myotonometric parameters and passive isokinetic parameters ranged from -0.29 to 0.48 ($P < 0.05$). *Significance*: The myotonometer was demonstrated to be a reliable tool and was able to quantify differences in the mechanical properties of myofascial tissues. The potential of this method for the assessment of myofascial pain syndromes requires further investigation.

1. Introduction

Myofascial trigger points (MTrPs) are painful areas in skeletal muscle that are associated with a palpable nodule within a taut band of muscle fibers (Thomas and Shankar 2013, Simons 2004). These trigger points can exist in active or latent states. An active MTrP is characterized by spontaneous and/or mechanical local and/or referred pain, while a latent MTrP is a sensitive spot whose pain is only elicited in response to different kinds of stimulation, such as compression (Simons and Travell 1999). Nevertheless, the diagnosis of both types of MTrPs is similar (Celik and Mutlu 2013).

Several methods have been employed over the years to measure the nature and characteristics of MTrP and taut bands. The usual diagnosis of an MTrP consists of the identification of a tender nodule within a taut band through palpation and the reproduction of the patient's symptoms in the case of active MTrPs (Simons 2008). However,

this specific diagnosis depends on the experience, training, and skills of the rater (Barbero *et al* 2013) and different inter-rater reliabilities have been reported (Gerwin *et al* 1997, Barbero *et al* 2012, Sha and Heimur 2012, Mayoral *et al* 2017). For that reason, today, the objective diagnosis and the quantification of its physical characteristics are crucial for improving treatment and clarifying the pathophysiology of MTrPs (Adigozali *et al* 2017).

Muscle stiffness and muscle tone are terms that have been often used interchangeably (Aarrestad *et al* 2004). Muscle tone can be defined as the resistance to a passive stretch that reflects neural factors and mechanical or viscoelastic properties and is a term frequently used in the clinical context (Aarrestad *et al* 2004, Masi and Hannon 2008, Gómez-Soriano *et al* 2014). On the other hand, muscle stiffness includes active stiffness (considering reflex response and voluntary muscle contraction) and passive stiffness (mechanical or viscoelastic properties) and is a term more frequently used in biomechanics (Mirbagheri *et al* 2001, Lorentzen *et al* 2010, Kubo 2014, Kubo *et al* 2015). The impact of MTrPs' development on muscle stiffness is still unknown.

More recently, new tools have been introduced to measure these muscle characteristics, such as magnetic resonance elastography, ultrasound elastography, and tensiomyography. Magnetic resonance elastography and ultrasound elastography are musculoskeletal imaging modalities used to characterize skeletal muscle properties, such as tissue passive stiffness (Sikdar *et al* 2008, 2009, Simons 2008, Basford and An 2009, Ballyns *et al* 2012, Thomas and Shankar 2013, Turo *et al* 2015). However, these sophisticated techniques can cause deformations of the evaluated tissue and could alter the mechanical properties of muscle tissues depending on their basal state (Viir *et al* 2006, Adigozali *et al* 2017). Tensiomyography is also a noninvasive method to measure the mechanical properties of superficial skeletal muscle, which has been used for the assessment of an MTrP and the treatment effects (Dahmane *et al* 2001, Calvo *et al* 2016, Calvo-Lobo *et al* 2017). Although all these techniques provide objective measures of muscle stiffness characteristics, they are not suitable for clinical use, as they are expensive, time-consuming, and require specialized staff training (Agyapong-Badu *et al* 2013).

Nevertheless, among these methods, the measurement of the resistance to passive stretch using an isokinetic dynamometry represents the gold standard assessment of muscle stiffness, being valid for assessing different muscle conditions (Boiteau *et al* 1995, Pisano *et al* 2000, Bressel and McNair 2002, Rabita *et al* 2005, Gómez-Soriano *et al* 2014) but has never been employed in the evaluation of myofascial tissue stiffness.

Currently, the myotonometer, a simple, reliable, noninvasive, portable, and painless tool, has already proven to be objective in measuring mechanical muscle properties. The myotonometer exerts a short mechanical pulse on the tested muscle, which causes a short-interval deformation in the muscle. The muscle responds to the mechanical stimulus in the form of damped oscillations recorded by an acceleration transducer on the testing end. After that, the device simultaneously computes the biomechanical parameters of oscillation frequency, stiffness, and logarithmic decrement (Lohr *et al* 2018, Chuang *et al* 2012). An important advantage is that the myotonometer set up, data acquisition, and real-time results analysis requires considerably less time than other tools. Indeed, this method does not require considerable expertise and equipment and it is practical for daily clinical use (Fröhlich-Zwahlen *et al* 2014, Van Deun *et al* 2018, Lo *et al* 2017). Moreover, to our knowledge, no myotonometric study has reported the reliability and the assessment of MTrPs.

Therefore, the primary objective of this study was to determine the ability of the myotonometer to identify, quantify, and compare the mechanical properties of the MTrP within its taut band, as well as to determine the inter-rater reliability of this measuring tool. As a secondary objective, the strength of the correlation between myotonometric and passive isokinetic parameters was established.

2. Methods

2.1. Design

The experimental design was a cross-sectional design conducted in accordance with The Declaration of Helsinki. This study was approved by the Toledo Hospital Clinical Research Ethics Committee (protocol number 134, 11/12/2015).

All participants completed a unique experimental session in which a myotonometry of a latent MTrP of the soleus muscle and its taut band was performed independently by two raters. Furthermore, passive resistive torque and soleus muscle extensibility was assessed by a third rater using an isokinetic dynamometer.

2.2. Participants

Healthy volunteers from the local community (accepted age range 18–55) with the presence of a latent medial MTrP of the right soleus muscle were recruited to participate in this study. All participants provided signed informed consent prior to the initiation of the assessment procedures.

The exclusion criteria included (1) any history of ipsilateral lower limb severe injury or intervention (e.g. fracture, surgical intervention); (2) reported pain or musculoskeletal injury in the ipsilateral lower limb in the previous month; (3) peripheral or central nervous system neurological disease; (4) altered sensitivity in the studied area; and (5) treatment of an MTrP in the triceps surae muscle during the 6 months previous to the study.

2.3. Procedures

All testing took place at the 'Hospital Nacional de Parapléjicos' in Toledo (Spain) in a single session. A specialized physiotherapist with more than 15 years of experience established the diagnosis of a latent medial MTrP of the right soleus muscle following the essential criteria proposed by Simons: focal spot muscle tenderness and pressure-elicited referred pain pattern not recognized by the participant as a usual pain complaint (Simons 2004, 2008). After that, this assessor located by manual palpation and marked on the skin the site of a medial MTrP of soleus muscle and a selected point within its taut band, 1 cm distal to the marked medial MTrP.

Participants were seated in an isokinetic dynamometer (Kin-Com, Chattanooga Group Inc.) with the right hip joint at 90° of flexion, the right knee slightly flexed at 10°, and the right ankle in a neutral position on a footplate aligned with the dynamometer rotation axis. The trunk and the right thigh were fixed with straps in order to provide stability. A trained physiotherapist, rater 1, conducted the isokinetic dynamometer assessment.

Myotonometric measurements for inter-rater reliability were carried out by two different qualified raters, rater 2 and rater 3 within the same session, trained in the use of the MyotonPRO technology.

In addition, another blinded researcher was responsible for entering outcome data on a data sheet.

2.4. Myotonometric assessment

Participants were seated on the Kin-Com dynamometer and they were instructed to completely relax. Myotonometric measures to compare the MTrP area and the taut band area were evaluated using the MyotonPRO device (Müomeetria AS, Estonia). The myotonometer was held perpendicular and stable in the measurement position. An automatically controlled preload (0.18 N) was applied with an automatic mechanical impulse to the contact area, with a duration of 15 ms and a constant force of 0.4 N (Bailey *et al* 2013, Fröhlich-Zwahlen *et al* 2014).

One measurement set of ten consecutive impulses (scan mode) was completed at each of the two marked points (the medial MTrP of the soleus muscle and its taut band) with a time interval of 1 s between each impulse. Mean data of each series were accepted if the coefficient of variation of the measurement set was inferior to 3% (Bailey *et al* 2013, Wang 2017). The parameters measured were (i) oscillation frequency (Hz) as an indicator of muscle tone, which characterizes the resting level of tension in the tissue; (ii) logarithmic decrement (arbitrary unit), which is considered as the ability of the muscle to restore its initial shape after being deformed (is inversely proportional to elasticity); and (iii) stiffness (N m^{-1}), which reflects the tissue resistance to the force deforming the muscle (Veldi *et al* 2000, Aird *et al* 2012, Mullix *et al* 2012, Bailey *et al* 2013, Chuang *et al* 2013).

2.5. Passive isokinetic assessment

During all assessments, participants were asked to remain as relaxed as possible and instructed to press a panic button to stop the assessment if it was necessary (Rabita *et al* 2005). Volunteers performed an initial warm-up trial at each velocity to familiarize themselves with the Kin-Com dynamometer (Chattanooga Group Inc.), which consisted of one set of five passive mobilizations at slow velocity (10° s^{-1}) and one set of ten passive mobilizations at fast velocity (180° s^{-1}) (Boiteau *et al* 1995, Rabita *et al* 2005, Gómez-Soriano *et al* 2014). Then, the measurement of muscle stiffness and muscle extensibility was performed.

Muscle stiffness was quantified by measuring the passive resistive torque of the triceps surae muscle when stretching was performed during the passive motion of the ankle joint from 35° of plantar flexion to 5° of dorsiflexion at both velocities. The resistive force testing at slow velocity evidences the mechanical response to a muscle stretch that does not evoke a reflex response. On the other hand, fast velocity represents total muscle stiffness, including reflex-mediated resistance (Boiteau *et al* 1995, Lamontagne *et al* 1998, Rydahl and Brouwer 2004, Gómez-Soriano *et al* 2014). Peak torque (PT (Nm)) and average torque (AT (Nm)) during ankle dorsiflexion were measured during both velocities as variables of the soleus muscle resistance (Gómez-Soriano *et al* 2014).

The passive extensibility of skeletal muscles can be defined as the ability of a muscle to lengthen without muscle activation, being the distance between an initial muscle length and the maximal length, both of which are dependent on the passive resistance to the stretch (Gajdosik 2001, Weppler and Magnusson 2010). To evaluate extensibility of the triceps surae muscle a passive range of motion at a constant velocity of 10° s^{-1} was imposed from 35° of ankle joint plantarflexion to (1) the maximum ankle dorsiflexion angle at which the soleus muscle generated a resistance of 200 N (AA_{200} (°)) (Gómez-Soriano *et al* 2014), and (2) the ankle dorsiflexion angle corresponding to the participant's perception endpoint of pain or stretch tolerance (AA_{Tol} (°)) (Weppler and Magnusson 2010).

2.6. Statistical analysis

Statistical analysis was performed using SPSS Version 21.0 (IBM Corporation, Armonk, NY) and the SigmaPlot Version 11.0 (Systat Software, Canada).

The Shapiro–Wilk test was performed to determine normal data distribution. An independent Student's *t*-test for the parametric data or a Mann–Whitney U test for nonparametric data was performed to compare myotonometric measurements performed at the medial MTrP with those obtained in the taut band of the soleus

muscle. Between-tissue effect sizes were calculated using Cohen's d coefficient. An effect size of less than 0.2 reflects a negligible mean difference; between 0.2 and 0.5, a small difference; between 0.5 and 0.8, a moderate mean difference; and 0.8 or greater, a large difference (Fritz *et al* 2012). To analyze correlations between the myotonometric variables of the medial MTrP of the soleus muscle and the myotonometry variables of the taut band, only the assessment made by rater 2 was selected.

Intra-class correlation coefficients ($ICC_{3,1}$) with a 95% confidence interval (CI) were calculated to determine relative reliability. An ICC of less than 0.50 was considered as poor reliability, 0.50–0.75 as moderate reliability, and greater than 0.75 as good reliability (Portney and Watkins 2009). Absolute reliability indices were expressed through standard error of measurement (SEM), SEM%, minimal detectable difference (MDD_{95}), and $MDD_{95\%}$. The SEM was estimated as the square root of the mean square error term from the analysis of variance (Stratford and Goldsmith 1997, Hopkins 2000, Weir 2005). The MDD at the 95% confidence level was calculated using formula $MDD_{95} = SEM * (\sqrt{2}) * 1.96$ (Fleiss 2007, Portney and Watkins 2009). SEM and MDD values can be used to determine whether a change in a group or in an individual is statistically significantly real (Chuang *et al* 2013). The smaller the SEM and the MDD, the greater the reliability (Atkinson and Nevill 1998, Weir 2005). SEM% (=(SEM/mean) × 100), where the mean is the mean for all observations from both assessments and $MDD_{95\%}$ (=(MDD_{95}/mean) × 100), where the mean is the mean for all measurements from both assessments, were used to facilitate interpretation of the results (Flansbjer *et al* 2005). The SEM% of <10% can be considered small and makes it possible to detect small changes that indicate real changes for a group of individuals (Flansbjer *et al* 2005, Chuang *et al* 2013). The $MDD_{95\%}$ of below 30% can be considered acceptable and that of below 10% can be considered excellent (Smidt *et al* 2002, Chuang *et al* 2013).

Pearson correlations (r) with a 95% CI were carried out to analyze the relationship between myotonometric measurements of myofascial tissue and passive isokinetic parameters. The strength of correlations was interpreted as low (0.00–0.25), fair (0.25–0.50), moderate to good (0.50–0.75), and good to excellent (>0.75) (Portney and Watkins 2009).

Only the assessment made by rater 2 was selected for the correlation analysis with the isokinetic assessment data.

All statistical analyses were performed considering a $P < 0.05$ significance level. Data are presented as mean ± standard deviation.

3. Results

Fifty participants were recruited and completed full testing procedures. The characteristics of the participants are described in table 1.

3.1. Myotonometry of the latent MTrP and its taut band

The Student's t-test showed statistically significant differences for stiffness parameter ($P < 0.05$) when compared with the medial MTrP area of the soleus muscle with its taut band area for the assessment of both raters. Differences in stiffness for rater 2 and rater 3 were 23.7 and 23.4 N m^{-1}, respectively, finding higher values in the taut band compared to the MTrP for both assessments. No significant differences in frequency and decrement were observed in any assessment.

The mean (SD and CIs) myotonometric variables of the medial MTrP as well as myotonometric variables of the taut band are plotted in table 2. Furthermore, table 2 shows P values and effect sizes on myofascial tissues comparison, where the MTrP showed a lower stiffness when compared with the taut band with $P < 0.05$ and effect size of $d = 0.465$ and $d = 0.431$ for rater 2 and rater 3, respectively.

3.2. Inter-rater myotonometry reliability

Table 3 shows ICCs and CIs, SEM (SEM%), and MDD_{95} ($MDD_{95\%}$) for the latent soleus medial MTrP and its taut band. A good general relative reliability (ICC > 0.75) was found for both the MTrP and taut band measures, with a total range of 0.86–0.97. The SEM ranged from 0.35–0.63 Hz for frequency, from 0.17–0.24 for decrement, and from 11.95–13.01 N m^{-1} for stiffness. The MDD_{95} was from 0.97–1.74 Hz for frequency, 0.48–0.68 for decrement, and 33.12–36.07 N m^{-1} for stiffness. All the SEM% values were below 10% except for the decrement parameter. In addition, the $MDD_{95\%}$ values for frequency and stiffness variables were below 12%, indicating a good absolute reliability. However, this reliability result was not for decrement variable, obtaining values greater than 40%. In figure 1, spaghetti graphs show data for all myotonometric variables, where each line connects values for both raters' measurements.

3.3. Association between myotonometry parameters within the MTrP and taut band

Pearson correlation coefficient analysis among the myotonometric variables of the medial MTrP of the soleus muscle and the taut band are shown in table 4. There were general positive correlations for frequency, decrement, and stiffness between the medial MTrP and its taut band.

Table 1. Sample characteristics ($n = 50$).

Age (years)	24.6 ± 7.9
Sex (male%)	58%
Height (m)	1.71 ± 0.08
Weight (kg)	68.64 ± 13.44
Body mass index (BMI)	21.12 ± 7.82

Note: Values are mean ± SD.

Table 2. Comparisons of frequency, decrement, and stiffness of the medial MTrP and its taut band of soleus muscle.

Variable	Rater	Myofascial tissue	Mean ± SD	Mean difference (95% CI)	*P* value	Effect size (d)
Frequency	2	MTrP	15.87 ± 1.75	−0.55 (−1.279 to 0.179)	0.138	0.299
		TB	16.42 ± 1.92			
	3	MTrP	16.17 ± 1.74	−0.49 (−1.245 to 0.249)	0.189	0.266
		TB	16.67 ± 2.01			
Decrement	2	MTrP	1.19 ± 0.20	0.012 (−0.074 to 0.098)	0.392	0.048
		TB	1.18 ± 0.22			
	3	MTrP	1.22 ± 0.21	0.045 (−0.041 to 0.131)	0.242	0.232
		TB	1.17 ± 0.22			
Stiffness	2	MTrP	304.84 ± 48.77	−23.72 (−43.981 to −3.459)	0.022[a]	0.465
		TB	328.56 ± 53.22			
	3	MTrP	305.52 ± 50.21	−23.40 (−44.971 to −1.829)	0.034[a]	0.431
		TB	328.92 ± 58.19			

Abbreviations: MTrP, medial myofascial trigger point of soleus muscle; TB, taut band of MTrP; SD, standard deviation; CI, confidence interval.
[a] $P < 0.05$.

Table 3. Inter-rater reliability of myofascial tissue myotonometry.

Measurement		ICC (95% CI)	SEM (SEM%)	MDD_{95} ($MDD_{95\%}$)
Frequency	MTrP	0.87 (0.78–0.92)	0.63 (3.93%)	1.74 (10.89%)
	TB	0.97 (0.95–0.98)	0.35 (2.11%)	0.97 (5.85%)
Decrement	MTrP	0.86 (0.76–0.98)	0.24 (20.38%)	0.68 (56.48%)
	TB	0.94 (0.89–0.97)	0.17 (14.76%)	0.48 (40.90%)
Stiffness	MTrP	0.93 (0.88–0.96)	13.01 (4.26%)	36.07 (11.82%)
	TB	0.95 (0.92–0.97)	11.95 (3.64%)	33.12 (10.08%)

Abbreviations: MTrP, medial myofascial trigger point of soleus muscle; TB, taut band of MTP; ICC, intraclass correlation coefficient; CI, confidence interval; SEM, standard error of measurement; SEM%, SEM divided by the mean of all measurements from the two assessments and multiplied by 100%; MDD, minimal detectable change; MDD%, MDD divided by the mean of all measurements from the two assessments and multiplied by 100%.

3.4. Association between myotonometry and passive isokinetic dynamometry

Pearson *r* values between the myotonometric measurement variables and the passive isokinetic measurement variables are presented in table 5. Correlations between the frequency and stiffness myotonometric parameters of the medial MTrP and the taut band with respect to passive resistive torque to ankle dorsiflexion at 10° and 180° s^{-1} were fair and statistically significant with a range of 0.33–0.48 ($P < 0.05$). The decrement parameters of the medial MTrP and the taut band were negatively correlated with passive resistive torque to ankle dorsiflexion at 10° s^{-1} ($r = -0.29$ to -0.31, $P < 0.05$) and positively correlated with ankle dorsiflexion tolerance angle ($r = 0.33$, $P < 0.05$).

4. Discussion

This is the first study that measures the MTrP area and its taut band area using a myotonometer device and the data support that not only could myotonometry be useful to understand mechanical properties of the myofascial

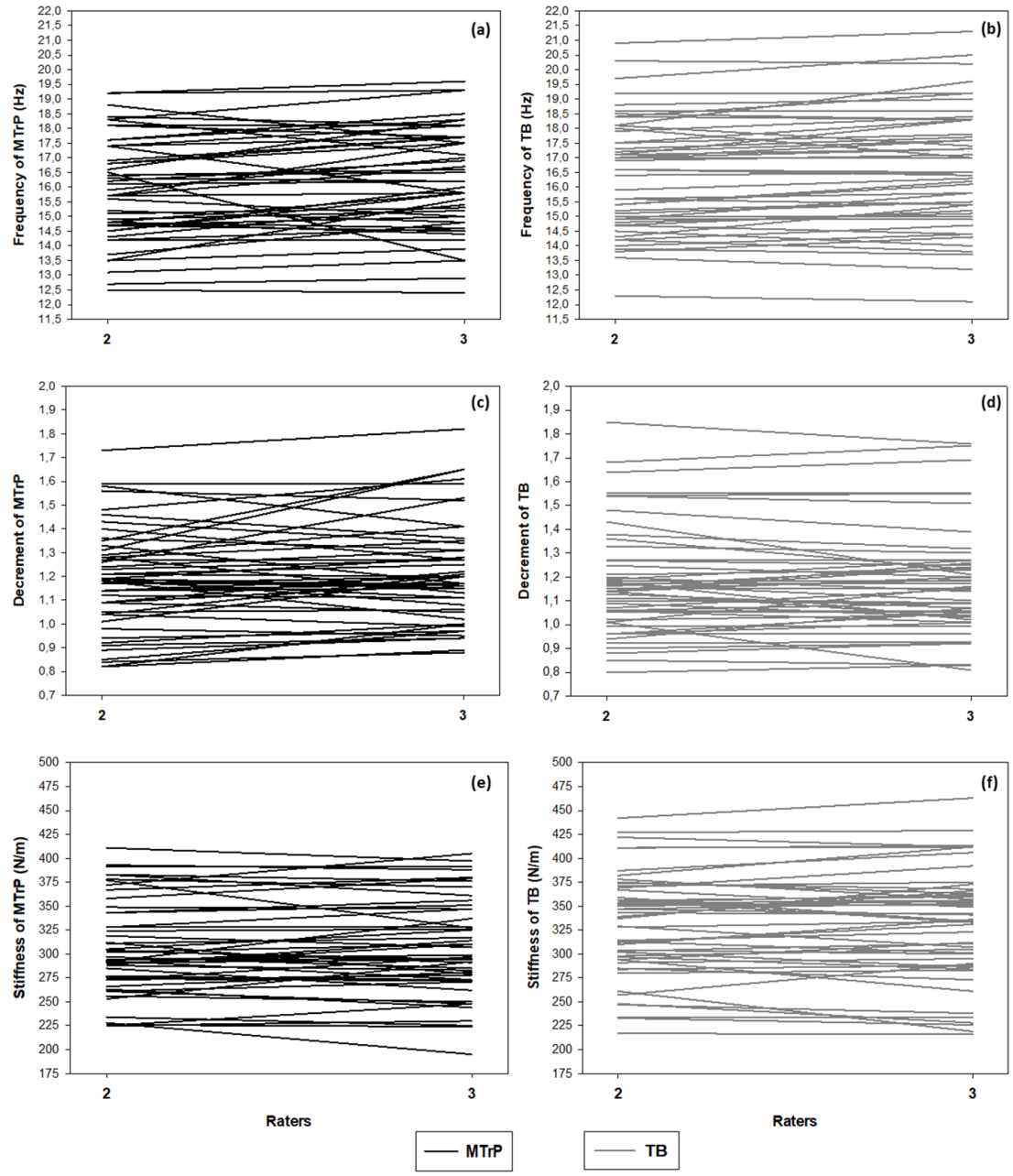

Figure 1. Individual subject profile ('spaghetti') plots show the measurements from the two raters for each variable: (a) frequency of MTrP (Hz), (b) frequency of TB (Hz), (c) decrement of MTrP, (d) decrement of TB, (e) stiffness of MTrP (N m^{-1}), and (f) stiffness of TB (N m^{-1}). Abbreviations: MTrP, medial myofascial trigger point of soleus muscle; TB, taut band of MTrP.

tissue, but it could also be useful for the diagnosis and detection of an MTrP. The results of the present study showed that (1) myotonometry is able to distinguish between the viscoelastic properties of a latent MTrP and its taut band, (2) myotonometry is a reliable technique for the assessment of the myofascial tissue, and (3) passive resistive torque of the triceps surae muscle measured with the isokinetic device positively correlates with the 'frequency' and 'stiffness' and negatively with 'decrement' as measured by the myotonometer.

4.1. Specific mechanical properties of the MTrPs

This study supports the ability of a myotonometer device to identify and detect differences between the mechanical properties of MTrPs and their surrounding myofascial muscle tissue (taut band).

Interestingly, we found lower values of stiffness in a latent soleus medial MTrP compared to its taut band in both raters' assessments. The higher the stiffness value, the more energy needed to modify the shape of the tissue. As expected, an excellent association between the myotonometric variables of the MTrP and taut band existed, considering we were evaluating points within the same myofascial structure in the soleus muscle.

Comparison of all these results with the literature is not possible because there are no reports on the myotonometric measurement of myofascial tissue. However, several studies have employed a myotonometer to quantify

Table 4. Correlation coefficients (r) and CIs between myotonometric measurements of the medial MTrP and its taut band.

		Frequency		Decrement		Stiffness	
Variable		MTrP	TB	MTrP	TB	MTrP	TB
Frequency	MTrP	—	0.86[a] (0.70 to 1.00)	0.19 (−0.09 to 0.48)	0.17 (−0.12 to 0.46)	0.91[c] (0.78 to 1.00)	0.83[a] (0.67 to 0.99)
	TB	—	—	0.15 (−0.14 to 0.43)	0.10 (−0.19 to 0.38)	0.79[a] (0.61 to 0.97)	0.95[a] (0.86 to 1.00)
Decrement	MTrP	—	—	—	0.81[a] (0.63 to 0.98)	0.23 (−0.05 to 0.51)	0.16 (−0.13 to 0.44)
	TB		—	—	—	0.16 (−0.13 to 0.45)	0.17 (−0.11 to 0.46)
Stiffness	MTrP	—	—	—	—	—	0.79[a] (0.62 to 0.97)
	TB	—	—	—	—	—	—

Abbreviations: MTrP, medial myofascial trigger point of soleus muscle; TB, taut band of MTrP.
[a] Significant correlation ($P < 0.001$).

and distinguish other different muscle conditions (Marusiak *et al* 2010, Chuang *et al* 2012, Fröhlich-Zwahlen *et al* 2014, Li *et al* 2017, Van Deun *et al* 2018, Wang 2017). For example, previous studies focusing on the assessment of relaxed, contraction, and stretching muscle states established differences in the evaluated myotonometric parameters in these different muscle conditions (Alamäki *et al* 2007, Gavronski *et al* 2007, Ditroilo *et al* 2011, Ikezoe *et al* 2012). Higher values of frequency, stiffness, and elasticity (inversely proportional to the decrement) in the contracted and stretched muscles with respect to the relaxed state were reported. Older adults present greater stiffness and frequency and lower elasticity than younger adults (Agyapong-Badu *et al* 2016). Findings from studies addressing muscle tone disorders show higher stiffness in the myotonometric measurement of skeletal muscle in Parkinson's patients with increased rigidity measured clinically (Marusiak *et al* 2010, Rätsep and Asser 2011) and in people with spasticity compared to healthy controls (Rydahl and Brouwer 2004). Similarly, myotonometric parameters differ depending on the position. According to Vain *et al* (2015), frequency and stiffness characteristics of the medial gastrocnemius muscle were significantly higher in the standing position compared to the supine position. Despite all these changes observed and the good reliability evidenced (Bizzini and Mannion 2003, Marusiak *et al* 2010, Zinder and Padua 2011, Aird *et al* 2012, Chuang *et al* 2012), we should keep in mind that some authors are critical of this method (Rihvk *et al* 2010, Pamukoff *et al* 2016).

Several methods, such as electromyography, biochemical analysis, tensiomyography, or elasticity imaging techniques (i.e. magnetic resonance elastography and ultrasound elastography), have been previously proposed in the literature to identify the presence and the type (active or latent) of MTrPs and to determine their tissue characteristics. A microanalytic and biochemical analysis showed higher concentrations for all analytes and lower pH in an active MTrP than latent and absent MTrPs in the upper trapezius muscle (Sha *et al* 2005). Furthermore, preliminary results of a nonpublished pathophysiological study show that MTrPs seem to present a higher content of glycosaminoglycans (Santafe Martinez *et al* 2015). This research about the composition of MTrPs could explain our findings of lower values of stiffness in the MTrP when compared with the surrounding area (taut band).

In this way, using ultrasound vibration sonoelastography, Sikdar *et al* (2008) found that there were differences in the echogenicity and echotexture of the MTrPs related to an increased stiffness both in active and latent MTrPs compared to normal tissue. Furthermore, magnetic resonance elastography studies in myofascial syndrome revealed that taut bands are indeed stiffer than the surrounding muscle in which they are found (Chen *et al* 2007, 2008, 2016). Another study showed the utility of ultrasound imaging to facilitate the detection of the taut band compared to the adjacent normal muscle tissue (Shankar and Reddy 2012). In addition, a recent study compared the use of sonoelastography and tensiomyography to detect stiffness differences among active MTrPs, latent MTrPs, and control points, concluding that only sonoelastographic strain index could detect higher values of stiffness at the area of active and latent MTrPs compared to control points (Calvo-Lobo *et al* 2017). Further studies will be required to focus on linking these findings with myotonometric analysis in order to provide a better understanding of the mechanical properties of myofascial tissues.

4.2. Inter-rater myotonometry reliability

In reference to inter-rater reliability, ICCs were very high for all myotonometric outcomes. Moreover, for frequency and stiffness parameters, the SEM% values lay below 10% and MDD% values lay below 20%, which

Table 5. Correlation coefficients (r) and CIs between myotonometric measurements and isokinetic measurements.

Variable		PT_{10}	AT_{10}	PT_{180}	AT_{180}	E_{200}	E_{Tol}	F_{Tol}
Frequency	MTrP	0.36[a] (0.08 to 0.63)	0.42[b] (0.15 to 0.68)	0.40[b] (0.13 to 0.66)	0.43[b] (0.17 to 0.69)	−0.16 (−0.45 to 0.14)	−0.03 (−0.33 to 0.27)	0.12 (−0.18 to 0.42)
	TB	0.33[a] (0.06 to 0.60)	0.38[b] (0.11 to 0.64)	0.43[b] (0.17 to 0.69)	0.46[b] (0.20 to 0.72)	−0.17 (−0.47 to 0.12)	−0.09 (−0.39 to 0.21)	0.10 (−0.40 to 0.20)
Decrement	MTrP	−0.27 (−0.55 to 0.01)	−0.31[a] (−0.58 to −0.03)	−0.16 (−0.45 to 0.13)	−0.15 (−0.43 to 0.14)	0.11 (−0.18 to 0.41)	0.33[a] (0.05 to 0.62)	0.20 (−0.09 to 0.50)
	TB	−0.31[a] (−0.58 to −0.03)	−0.29[a] (−0.56 to −0.01)	−0.18 (−0.47 to 0.10)	−0.18 (−0.46 to 0.11)	0.10 (−0.20 to 0.40)	0.29[a] (0.00 to 0.58)	0.15 (−0.45 to 0.15)
Stiffness	MTrP	0.40[b] (0.13 to 0.67)	0.45[b] (0.19 to 0.71)	0.45[b] (0.19 to 0.71)	0.48[a] (0.23 to 0.73)	−0.26 (−0.55 to 0.03)	−0.19 (−0.48 to 0.11)	0.07 (−0.37 to 0.23)
	TB	0.35[a] (0.08 to 0.63)	0.42[b] (0.16 to 0.68)	0.43[b] (0.17 to 0.69)	0.45[b] (0.19 to 0.71)	−0.18 (−0.48 to 0.11)	−0.14 (−0.44 to 0.16)	0.05 (−0.25 to 0.35)

Abbreviations: MTrP, medial myofascial trigger point of soleus muscle; TB, taut band of MTrP; PT_{10}, PT at 10° s^{-1}; AT_{10}, AT at 10° s^{-1}; PT_{180}, PT at 180° s^{-1}; AT_{180}, AT at 180° s^{-1}; E_{200}, ankle angle corresponding to 200 N; E_{Tob}, ankle dorsiflexion tolerance angle; F_{Tob}, force required for E_{Tol}.

[a] Significant correlation ($P < 0.05$).

[b] Significant correlation ($P < 0.01$).

can be considered small and acceptable. The SEM (SEM%) and MDD_{95} ($MDD_{95\%}$) of the taut band assessment appear to be smaller than those of the MTrP assessment, indicating a more reliable measurement.

It is important to note that no study has evaluated inter-reliability in myofascial tissues before. Nevertheless, our reliability results are in concordance with previous studies using myotonometry in healthy subjects, where ICC scores were superior to 0.60 for frequency, decrement, and stiffness parameters (Van Deun *et al* 2018, Viir *et al* 2006). In addition, Sakkool *et al* (2016) found good inter-reliability in healthy children for all measured muscles in their study, except for rectus femoris. Our results, except for the decrement variable, regarding absolute reliability are in line with other study results where inter-reliability was studied in healthy subpopulations (Agyapong-Badu *et al* 2013, Van Deun *et al* 2018). However, Van Deun *et al* (2018) also found lower relative reliability in individuals with paratonia (Lohr *et al* 2018). Similar SEM% and MDD% values but in intra-rater reliability studies were found by Lohr *et al* (2018) and Van Deun *et al* (2018) in healthy adults and by Chuang *et al* (2013) in subacute stroke patients. It must be emphasized that these authors calculated absolute reliability through a different procedure using ICCs to obtain SEM values.

In the scientific literature, myotonometric reproducibility between qualified physiotherapists and novice users has also been evaluated. Agyapong-Badu *et al* (2013) demonstrated good and excellent inter-rater reliability in novice physiotherapists for the three myotonometric parameters in young and older healthy males. In an infantile cerebral palsy study, reliability in novice users was also studied in relaxed and contracted muscles, showing moderate to high results with some exceptions (Aarrestad *et al* 2004). According to these studies, myotonometric measurements provide objective data that are not influenced by the experience of the rater (Leonard *et al* 2003) in contrast to other MTrP assessments, such as manual palpation (Barbero *et al* 2012), imaging techniques (Takla *et al* 2016), or tensiomyography (Tous-Fajardo *et al* 2010).

4.3. Myotonometry as a measure of muscle tone

Passive resistive torque while stretching a muscle using an isokinetic device is considered as a gold standard to measure muscle stiffness and quantify muscle tone disorders (Lamontagne *et al* 1998, Rabita *et al* 2005). On the other hand, myotonometry provides the assessment by quantifying tissue displacement with respect to perpendicular compression force. However, very few studies have compared myotonometric measurements with 'the resistance to passive movement' paradigm (Leonard *et al* 2001, Rydahl and Brouwer 2004, Li *et al* 2017). Li *et al* (2017) reported similar correlation coefficients to our study between the total stiffness at $100° s^{-1}$ controlled by a servomotor and the degree of muscle deformation with respect to the compression applied perpendicularly to the muscle measured with another myotonometer device. Our significant but 'low to moderate' correlations could be due to the different concept of muscle stiffness assessment. In the case of myotonometry, muscle stiffness is measured by the resistance of a perpendicular force to a determined point (Agyapong-Badu *et al* 2013, 2016). On the other hand, muscle stiffness quantified by isokinetic dynamometry is obtained by a longitudinally applied force to all the muscle-tendon and articular structures (Bressel and McNair 2002).

Other studies have revealed the relationship between myotonometry and other muscle stiffness assessment tools. Ditroilo *et al* (2011) studied the influence of the position of the knee joint on contractile and mechanical properties of the biceps femoris muscle by myotonometry and tensiomyography, concluding myotonometry presents higher sensitivity to detecting changes in the three myotonometric parameters (frequency, decrement, and stiffness). Nevertheless, no correlations between these methods were realized in this study. In another study where muscle stiffness in Parkinson's disease patients was evaluated, myotonometric parameters have been shown to correlate with electromyographic recordings in the biceps brachii muscle. So, it is proposed that myotonometry could be an alternative method to assess muscle passive stiffness of skeletal muscle (Marusiak *et al* 2010).

Further research in both myotonometric assessment as well as isokinetic assessment is needed, taking into account latent and active MTrPs in different muscles.

4.4. Limitations

These results should be interpreted with caution since it should be emphasized that our study was carried out in latent MTrPs of asymptomatic adults. Future studies might focus on studying the mechanical properties of active MTrPs in persons with myofascial pain syndrome. Another relevant point is that a control point outside the taut band of the muscle was not included in this study. The comparison of the MTrP and its taut band with a non-myofascial point would increase the understanding of myofascial tissue properties since the comparison of these structures has not yet been studied in the scientific literature. Furthermore, the application of the myotonometry method on more superficial or deeper muscles should be considered, taking into account the body mass index. We have not assessed intra-rater reliability but numerous myotonometric studies have shown a moderate to good intra-rater reliability within session (Lidström *et al* 2009, Chuang *et al* 2012, Lohr *et al* 2018) and between sessions (Bizzini and Mannion 2003, Aird *et al* 2012, Lohr *et al* 2018). The absence of myoelectric activities of triceps surae muscle has not been confirmed by electromyography and this is another acknowledged limitation.

Finally, to enhance the applicability and interpretability of the myotonometric measurements, further studies are required to provide validity and reference values to examine potential applications of the MyotonPRO device in the diagnosis of and regular clinical practice in myofascial syndrome.

5. Conclusion

Our findings suggest that myotonometry is a reliable method to measure latent MTrPs and is able to detect differences in their physical characteristics with respect to taut bands. In addition, the moderate but significant correlation observed between myotonometry and the resistive torque measured by dynamometry suggests that myotonometry could be an easy and low-cost tool for measuring muscle stiffness. However, it is necessary to establish whether both techniques assess the same stiffness characteristics of the muscle tissues.

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