Myotonometry Reliably Measures Muscle Stiffness in the Thenar and Perineal Muscles

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ABSTRACT

Purpose: The authors investigated the reliability of myotonometry-measured muscle tone in the thenar and perineal muscles. **Methods:** Participants were women aged 18–50 years who were asymptomatic for thumb and pelvic floor dysfunction (interrater study $n = 20$; intrarater study $n = 43$) or who were symptomatic for vulvodynia (interrater study $n = 14$; intrarater study $n = 32$). Mechanical properties (stiffness, frequency, decrement, relaxation time, and creep) of the muscles were measured using a myotonometer (MyotonPRO) while the muscles were in a relaxed state. Measures were performed twice by two assessors. Intra- and interrater reliability were determined using intra-class correlation coefficients (ICCs) and absolute reliability using the standard error of measurement and a minimum detectable change. **Results:** The primary property of interest, muscle stiffness, showed very good interrater (ICC 0.85–0.86) and intrarater (ICC 0.82–0.88) reliability in the thenar eminence. In the perineal muscles, reliability results ranged from good to very good for interrater (ICC 0.70–0.86) and intrarater (ICC 0.80–0.91) reliability for muscle stiffness. Absolute reliability was confirmed, with all measures showing minimal variance. **Conclusions:** Muscle stiffness of the smaller muscles of the body can be reliably measured using the MyotonPRO. The device could be used as a reference standard in the development of a digital palpation scale that would facilitate accurate diagnosis of muscle tone.

Key Words: muscle; perineum; reproducibility of results; thumb.

RÉSUMÉ

Objectif : étudier la fiabilité de la raideur musculaire mesurée par myotonométrie dans les muscles de l'éminence thénar et du périnée. **Méthodologie :** Les participantes étaient des femmes âgées de 18 à 50 ans ne présentant aucun symptôme de dysfonctionnement du pouce ni du plancher pelvien (étude interévaluateur $n = 20$; étude intra-évaluateur $n = 43$) ou présentant des symptômes de vulvodynie (étude interévaluateur $n = 14$; étude intra-évaluateur $n = 32$). Les propriétés mécaniques (raideur, fréquence, décrement, temps de relaxation et fluage) des muscles au repos ont été mesurées à l'aide d'un myotonomètre (MyotonPRO). Les mesures ont été prises deux fois par deux évaluateurs. La fiabilité intra-évaluateur et interévaluateur a été déterminée à l'aide des coefficients de corrélation intraclasse (CCI) et la fiabilité absolue à l'aide de l'écart type de mesure et du changement minimal détectable. **Résultats :** la propriété d'intérêt principal, la raideur musculaire, a montré une très bonne fiabilité interévaluateur (CCI 0,85-0,86) et intra-évaluateur (CCI 0,82-0,88) pour l'éminence thénar. Concernant les muscles du périnée, les résultats de fiabilité variaient de bons à très bons pour la fiabilité interévaluateur (CCI 0,70-0,86) et intra-évaluateur (CCI 0,80-0,91) pour la raideur musculaire. La fiabilité absolue a été confirmée, toutes les mesures montrant une variabilité minimale. **Conclusions :** la raideur musculaire des plus petits muscles du corps peut être mesurée de manière fiable à l'aide du MyotonPRO. L'appareil pourrait être utilisé comme norme de référence dans la conception d'une échelle numérique de palpation qui faciliterait le diagnostic exact du tonus musculaire.

A common finding in the clinical assessment of musculoskeletal pain disorders in both peripheral muscles and pelvic floor muscles (PFMs) is increased muscle

tone (defined by the resistance to a change in muscle length, also described as stiffness, tension, or activity) in the affected area.^{1–4} Increased tone in the PFMs has

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Contributors: All authors designed the study; or collected, analyzed, or interpreted the data; and drafted or critically revised the article and approved the final draft.

Competing Interests: None declared. Adam L. Bryant is supported by a National Health and Medical Research Council R.D. Wright Biomedical Fellowship. Helena C. Frawley is supported by a National Health and Medical Research Council Health Professional Fellowship.

No commercial party having a direct financial interest in the results of the research supporting this article has or will confer a benefit on the authors or any organization with which the authors are associated.

Financial support for the research was provided by a Physiotherapy New Zealand Grant (provided in 2012) and a Physiotherapy Research Foundation Grant (T12-CWH001). Funding supporters had no involvement in the design of this study; the collection, analysis, or interpretation of the data; writing reports; or submitting this article for publication.

Acknowledgements: The authors thank Dr. Margaret Staples, Statistician, Cabrini Health, for her assistance with calculating absolute reliability values.

Physiotherapy Canada 2017; 69(2);104–112; doi:10.3138/ptc.2015-85

been postulated to be a primary factor in many bladder, bowel, and sexual pain disorders.⁵ Researchers have attempted to quantify PFM tone using surface electromyography,^{2,6,7} pressure manometry,^{8–11} and digital palpation,^{4,12–15} but these tools lack validity and specificity for quantifying muscle tone because they do not provide a direct measure of resistance to change in muscle length. Furthermore, there are no standardized digital palpation scales for tone in common clinical usage that have been assessed against a gold standard in either PFMs or peripheral muscles; the current assessment of muscle tone is largely based on the subjective opinions of expert clinicians.^{3,5,16,17}

Treatment guidelines for chronic pelvic pain conditions frequently recommend therapies to reduce the perceived level of muscle tone,^{2,18–21} but the empirical evidence supporting the efficacy of these treatments is limited.^{20,22,23} The lack of a reliable and objective method for assessing muscle tone in the pelvic floor adds to the difficulty of understanding the relationship between muscle tone and chronic pelvic pain or other pelvic floor disorders. The primary outcome measure of interest in this study was muscle stiffness, defined as resistance to deformation, because this particular property of muscle relates directly to the clinical measurement of tone felt during palpation of the muscles.²⁴ Passive stiffness is defined as the ratio of the change in the passive resistance or passive force (ΔF) to the change in the length displacement (ΔL), or $\Delta F/\Delta L$.²⁵

Myotonometry provides an objective way to quantify physiological properties of muscle tone, including stiffness. The MyotonPRO is a small, non-invasive, handheld myotonometer that provides an objective measure of the mechanical properties of *in vivo* muscles.²⁶ To date, the device has shown good validity^{27–29} and high reliability^{30–33} when used with the larger muscles of the upper and lower limbs.

Previous studies have predominantly focused on the larger muscles of the body^{27,29,30,32–37} and have not reported myotonometry-derived measures of smaller muscles, such as the intrinsic muscles of the hand or the perineal muscles of the pelvic floor, which are the interest of this study. The perineal muscles are composed of the superficial transverse perineal and bulbospongiosus muscles, both of which connect midline at the central perineal body,^{38,39} and the small, fleshy muscle bundles of the perineal muscles, which occur on either side of the perineal body.³⁹ The perineal muscles are classically described as part of the perineum, rather than as part of the PFMs.³⁸ However, because they apply tension to the connecting fascia and ligaments to support the pelvic organs and maintain the closing pressure of the bowel and bladder sphincters, they are considered functionally to be part of the PFMs.^{40–42} We chose the thenar muscle, the abductor pollicis brevis, as a peripheral

muscle to measure with the MyotonPRO because its small size is comparable to the perineal muscles, it is easily accessible for measurement, and it has the potential to be used as a training model for a digital palpation scale to be developed using the MyotonPRO as a reference standard for clinicians.

The primary aim of this study was to quantify the interrater and intrarater reliability of the stiffness measures of the thenar eminence (in an asymptomatic cohort) and perineal muscles (in asymptomatic and symptomatic cohorts), as assessed using the MyotonPRO. We hypothesized that the MyotonPRO would show very good reliability for stiffness in the thenar eminence measurements and good to very good reliability in the perineal muscles, although the potential challenges of accessing the muscles could affect the reliability of our measurements. Our secondary aim was to estimate the interrater and intrarater reliability of the four other muscle properties measured by the MyotonPRO—frequency, decrement, relaxation time, and creep—in both the thenar and the perineal muscles. We hypothesized that the MyotonPRO would similarly show very good reliability for the other muscle properties in the thenar eminence measurements and good to very good reliability in the perineal muscles.

METHODS

Participants

A total of 43 women (asymptomatic of thumb and pelvic floor dysfunction) and 32 women (symptomatic of localized provoked vulvodynia) aged 18–50 years were recruited by sending out a printed media invitation and placing advertisements on Facebook. The symptomatic cohort underwent a clinical, pre-screening cotton swab diagnostic test, which we performed to confirm pain in the vulval area before we enrolled the women in the study; this is part of the standard clinical screening for vulvodynia.^{43,44} All recruitment and assessment took place over two discrete time periods—a 3-week period (asymptomatic cohort) and a 4-week period (symptomatic cohort).

Exclusion criteria screening occurred via an online survey. Exclusion was based on a positive response for any one of the following: clinically significant score (for the asymptomatic cohort, a total score ≥ 4) on the self-administered Australian Pelvic Floor Questionnaire,⁴⁵ pain in the pelvic or thumb regions (asymptomatic cohort), conditions or medications that alter muscle tone or sensation, neurological conditions, less than 6 months postpartum, lactation, pregnancy, or post-menopausal status. The study received approval from the local institutional Human Research Ethics Committee (HREC nos. 1238707 and 1340233). All participants were given a Plain Language Statement and provided written informed consent.

Figure 1 MyotonPRO with 100-millimetre probe.

On the basis of an intra-class correlation coefficient (ICC) of 0.85 with a 95% CI: 0.70, 0.99 for muscle stiffness,⁴⁶ a sample size of 15 was calculated for both intrarater and interrater reliability in the perineal and thenar muscles. However, sample sizes were increased a priori to include all eligible participants who applied, which provided a sample size of 20 for the interrater assessment and of 43 for the intrarater assessment in the asymptomatic cohort. Because of the second assessor's limited availability, the sample size for the symptomatic cohort assessment was 14 for interrater assessment and 32 for intrarater assessment.

Equipment

Muscle properties were assessed using a myotonometer, the MyotonPRO (Myoton AS, Tallinn, Estonia), and applying standardized measurement protocols for the device.²⁶

The probe or testing end of the device was placed perpendicular to the skin surface directly above the muscle to be measured, and a device-set pre-pressure of 0.18 newtons was applied to maintain skin contact and slightly compress the subcutaneous tissues. A brief mechanical impulse lasting 15 microseconds was applied to the muscle at a force of 0.40 newtons, resulting in a total applied force of 0.58 newtons. The resulting damped oscillations of the muscle were recorded by an accelerometer, and numerical values were calculated to show the muscle's biomechanical and viscoelastic properties.

The MyotonPRO measures five muscle properties: oscillation frequency (in hertz), which is the intrinsic tension of the muscle in its passive state; dynamic stiffness (in newtons per metre), the resistance to deformation; logarithmic decrement, the elasticity of the muscle; mechanical stress relaxation time (in milliseconds), the time it takes the muscle to restore its shape from deformation; and creep (in Deborah number), the gradual elongation of the muscle over time when placed under constant tensile stress.^{26,29,33,34,36,37} Measurement results were recorded and stored on the MyotonPRO for offline data analysis.

A standard probe, 30 millimetres long and 3 millimetres wide, was used for thenar measures. To meet health and safety requirements, a single-patient-use 100 millimetre $\times$ 3 millimetre perineal probe was designed and calibrated by the manufacturer for perineal application (see Figure 1).

Experimental procedure

Myoton measures of the thenar eminence and perineal muscles were taken on two occasions, 1 hour apart, using standardized positions, instructions, and measurement protocols. On each of the two measurement occasions, the two assessors performed the measurements in a fixed order (Assessor 1, followed by Assessor 2) less than 5 minutes apart. The order of assessors was randomized only in the symptomatic cohort.

After a software update to the MyotonPRO was released, the ability to randomize the order of testing became easier (i.e., without the risk of losing the data sequence); therefore, randomization of test order was applied to the symptomatic cohort. Measurements were taken on both sides of the body, immediately after one maximum voluntary contraction (MVC), while the muscle was in a relaxed state. Instructions to the participant regarding how to perform an MVC were standardized—for example, for the thumb, “Squeeze your little finger and thumb together as strongly as you can, and hold it for 1 second,” and for the perineum, “Lift and squeeze your pelvic floor muscles as strongly as you can, and hold for 1 second.” Participants were instructed immediately after the MVC to “let the muscles relax and rest now” to prepare for the relaxation measurement using

the MyotonPRO. Both assessors were pelvic floor physiotherapists, each having more than 20 years' experience in assessing and treating PFM dysfunction. The MyotonPRO is not available commercially and has not been used before in pelvic floor research; hence, both assessors were initially novel users of the instrument. A training protocol ensured that they gained experience and familiarity with the device before collecting the data.

Measures for the thenar eminence were taken with participants in a seated position, with elbows at 90 degrees, forearms supinated, and hands supported on a cushion. The site of measurement in the thenar eminence was located by measuring halfway between the scaphoid bone and the first phalanx radial sesamoid bone of the metacarpal phalangeal joint. The muscle belly of the abductor pollicis brevis was palpated to verify location, and a marker was positioned.

Measures for the perineal muscles were taken with participants in bent-knee supine position, with the left leg supported by a pillow and the right leg supported by the assessor, to ensure that the legs were symmetrical and relaxed during measurement. The site of measurement was located by visual observation (perineal muscle in-drawing) and palpation of the largest area of muscle bulk during contraction of the perineal muscles on either side of the central perineal body. This was identified as the junction of the muscle bellies of the superficial transverse perineal and the bulbospongiosus muscles. This area of muscle bulk was determined to be the optimum location for obtaining accurate, external perineal muscle measurements because it appeared to contain the most contractile portion of the perineal muscles, as identified by palpation. A physical marker was positioned to ensure that both assessors took the measurement at the same site.

The MyotonPRO was positioned at the measurement location and held while the device performed the pre-defined series of measurements: a multi-scan mode of three mechanical impulses, 1 second apart; the average value was used for analysis.

Statistical analysis

Statistical analysis was conducted using the IBM SPSS Statistics, version 21 (IBM Corp., Armonk, NY). To determine whether there were differences between the demographic variables of each cohort, analysis of variance and chi-square tests were completed. Statistical significance for these tests was set at $p < 0.05$. Intrarater and interrater relative reliability were tested using ICC coefficients (two-way mixed model, averaged measures) with 95% CI. Statistical assumptions of normal distribution and homogeneity of variance for ICC analysis were assessed visually and met specific standards. Point estimates of the ICCs were interpreted as follows: less than 0.20 = poor; 0.21–0.40 = fair; 0.41–0.60 = moderate; 0.61–0.80 = good; and 0.81–1.00 = very good.⁴⁷ The standard error

of measurement (SEM), a reliability index that indicates the extent to which a score varies on repeated measurements, was calculated as follows: $SEM = SD\sqrt{1 - ICC}$.⁴⁸ A minimum detectable change (MDC) at the 95% CI was calculated using the SEM values as follows: $MDC_{95} = SEM = \sqrt{2} \times 1.96$.⁴⁸ A measure was interpreted as being stable if the difference in the means between the test and retest measures was less than the MDC_{95} .

RESULTS

The demographic and clinical characteristics of the participants are presented in Table 1. No significant differences were found between the two cohorts for the variables of age ($p = 0.41$) and body mass index ($p = 0.18$). Participants were predominantly nulliparous, European–Caucasian, and right-handed.

Among the parous participants, vaginal delivery was the most commonly reported mode of delivery when all childbirths were accounted for (asymptomatic cohort 91%, symptomatic cohort 75%). In both cohorts, participants were in varying phases of their menstrual cycle (0–24 d).

Table 2 summarizes the relative (ICC, 95% CI) and absolute (SEM and MDC_{95}) reliability values of the MyotonPRO muscle stiffness measures from both the thenar and the perineal muscles. The muscle stiffness ICC values for the thenar eminence showed very good intrarater and interrater reliability, and those for the perineal muscles showed good to very good intrarater and interrater reliability. All values were within the very good range for the symptomatic perineal cohort. Absolute reliability measures reflected stable stiffness values in both muscles on test–retest.

Table 3 summarizes the relative (ICC, 95% CI) and absolute (SEM and MDC_{95}) reliability values of the remaining four muscle properties, measured from both

Table 1 Demographic Summary of Participants

Variable	No. (%) of participants*	
	Asymptomatic (<i>n</i> = 43)	Symptomatic (<i>n</i> = 32)
Age, y, mean (SD)	30.9 (9.2)	29.25 (7.3)
BMI, kg/m ² , mean (SD)	23.76 (3.62)	22.72 (2.84)
Parity (nulliparous/parous)†	32 (74)/11 (26)	24 (75)/8 (25)
Vaginal delivery only	7 (64)	4 (50)
Caesarean delivery only	1 (9)	2 (25)
Both vaginal and Caesarean delivery	3 (27)	2 (25)
Oral contraceptive pill	13 (30)	15 (47)
Ethnicity		
European–Caucasian	37 (86)	26 (81)
Asian	4 (9)	2 (6)
Indian	1 (2)	3 (9)
African	1 (2)	1 (3)
Right-hand dominant	36 (84)	29 (91)

*Unless otherwise indicated.

†Percentages do not total 100 because of rounding.

Table 2 Muscle Stiffness Reliability Results Measured in Newtons per Metre

Muscle	Interrater results				Intrarater results			
	Mean (95% CI)	Interrater ICC (95% CI)	SEM	MDC ₉₅	Mean (95% CI)	Intrarater ICC (95% CI)	SEM	MDC ₉₅
Thenar		<i>n</i> = 20				<i>n</i> = 43		
Right side	321.97 (289.74, 354.19)	0.85 (0.62, 0.94)	16.44	45.57	314.19 (279.77, 348.61)	0.82 (0.67, 0.90)	17.56	48.67
Left side	321.78 (275.07, 368.49)	0.85 (0.63, 0.94)	23.83	66.05	319.06 (284.74, 353.38)	0.90 (0.81, 0.94)	17.51	48.52
Perineal (asymptomatic cohort)		<i>n</i> = 20				<i>n</i> = 43		
Right side	106.83 (89.35, 124.31)	0.70 (0.23, 0.88)	8.92	24.71	118.25 (99.99, 136.51)	0.85 (0.73, 0.92)	9.31	25.81
Left side	112.92 (95.91, 129.93)	0.77 (0.41, 0.91)	8.68	24.05	122.27 (102.81, 141.73)	0.80 (0.62, 0.89)	9.93	27.52
Perineal (symptomatic cohort)		<i>n</i> = 14				<i>n</i> = 32		
Right side	147.31 (128.26, 166.36)	0.83 (0.46, 0.94)	9.72	26.93	142.85 (127.04, 158.66)	0.91 (0.81, 0.96)	8.07	25.81
Left side	159.08 (144.10, 174.05)	0.86 (0.57, 0.96)	7.64	21.18	155.05 (134.39, 175.70)	0.88 (0.75, 0.94)	10.54	29.20

ICC = intra-class correlation coefficient; SEM = standard error of measurement; MDC₉₅ = minimum detectable change at 95% CI.

the thenar and the perineal muscles. In the thenar eminence, intrarater and interrater reliability ICC values showed good to very good reliability for all muscle properties measured on the right side and very good reliability for all properties measured on the left side. In the perineal muscles, intrarater and interrater reliability ICC values ranged from fair to very good in the asymptomatic cohort, with no clear pattern between right and left sides of the body, and were very good in the symptomatic cohort for all muscle properties measured on both sides. Absolute reliability measures reflected stable values for all muscle properties in both muscles on test–retest.

DISCUSSION

To our knowledge, this is the first study in which myotonometry has been used to assess the mechanical properties of smaller human muscles. Our results showed good to very good inter- and intrarater reliability (i.e., ICC values of 0.70–0.91 with stable absolute reliability) for thenar and perineal muscle stiffness; this indicates that the MyotonPRO can be used reliably on the small muscles of the thumb and perineum of asymptomatic and symptomatic women. More important, these ICC values compare favourably with previous studies that have examined larger muscle groups^{27,29,30,32–37} (e.g., quadriceps). A small difference in ICC values was found for muscle stiffness of the perineal muscles (good to very good in the asymptomatic group vs. very good in the symptomatic group), which may indicate that, for muscles that are difficult to measure, a learning curve could be involved in using the MyotonPRO reliably; however, on easy-to-measure muscles (e.g., the thenar), this was not the case: All muscle stiffness ICC measures showed very good reliability.

The other four muscle properties measured (frequency, decrement, relaxation time, and creep) also showed good

to very good intrarater and interrater reliability, with the exception of two: frequency (ICC 0.38) and relaxation time (ICC 0.59) of the left perineal muscle of the asymptomatic cohort. Although two results had low ICC values, all other measures showed stable absolute reliability; this, combined with the muscle stiffness ICC values obtained, indicates that the device is reliable for the clinically relevant measurements needed to assess muscle stiffness.

We encountered measurement difficulties specific to the perineal muscles: that is, the location of the muscles and the length of the probe. For example, marked anatomical variation was observed among participants of the angle of the perineal muscles between the perineal body, the ischial tuberosity, and the vaginal introitus, on one hand, and the location of the muscle belly, on the other. In some participants, the shape of the pelvis resulted in a more acute angle of the muscles from the perineal body to the muscle insertion points at the ischial tuberosity and the vaginal introitus. The resultant acute angle made it difficult to obtain accurate readings and required multiple measures to achieve the three accurate readings required by the device in multi-scan mode. It was also difficult to use the 100-millimetre probe because its length required the assessors to stabilize their arm during measurement to prevent any movement that might affect its accuracy.

Taken together, these probe placement difficulties may have affected the reliability of the measurement of the perineal muscles. However, the good to very good stiffness reliability values obtained for the perineal muscles indicate that although measurement was challenging in this location, the MyotonPRO appeared to be a reliable method in this study. These challenges highlight the unique nature of the perineal muscles of the pelvic floor, and they point to the requirement for muscle-specific

Table 3 Muscle Properties Reliability Results

		Interrater results				Intrarater results			
Muscle	Property (measured in)	Mean (95% CI)	Interrater ICC (95% CI)	SEM	MDC ₉₅	Mean (95% CI)	Intrarater ICC (95% CI)	SEM	MDC ₉₅
Thenar		<i>n</i> = 20				<i>n</i> = 43			
Right side	Frequency (Hz)	19.44 (18.15, 20.72)	0.81 (0.52, 0.92)	0.66	1.82	19.35 (18.02, 20.67)	0.78 (0.60, 0.88)	0.68	1.88
	Decrement	1.35 (1.20, 1.50)	0.76 (0.39, 0.90)	0.08	0.22	1.10 (1.24, 1.56)	0.74 (0.53, 0.86)	0.08	0.22
	Relaxation time (ms)	14.81 (13.38, 16.24)	0.78 (0.46, 0.91)	0.73	2.02	15.17 (13.82, 16.51)	0.84 (0.71, 0.92)	0.69	1.91
	Creep (D)	0.91 (1.74, 0.07)	0.76 (0.40, 0.91)	0.42	1.18	0.93 (0.85, 1.00)	0.84 (0.70, 0.91)	0.04	0.11
Left side	Frequency (Hz)	19.36 (17.91, 20.81)	0.87 (0.68, 0.95)	0.74	2.05	19.52 (18.15, 20.88)	0.87 (0.75, 0.93)	0.70	1.93
	Decrement	1.35 (1.27, 1.43)	0.93 (0.82, 0.97)	0.04	0.11	1.43 (1.32, 1.53)	0.87 (0.77, 0.93)	0.05	0.15
	Relaxation time (ms)	14.92 (13.11, 16.73)	0.82 (0.55, 0.93)	0.93	2.57	15.02 (13.67, 16.37)	0.88 (0.78, 0.94)	0.69	1.91
	Creep (D)	0.91 (0.81, 1.01)	0.82 (0.55, 0.93)	0.05	0.14	0.92 (0.84, 0.99)	0.88 (0.78, 0.94)	0.04	0.11
Perineal (asymptomatic cohort)		<i>n</i> = 20				<i>n</i> = 43			
Right side	Frequency (Hz)	10.44 (9.93, 10.95)	0.73 (0.33, 0.89)	0.32	0.72	10.91 (10.07, 11.74)	0.80 (0.63, 0.89)	0.43	1.18
	Decrement	0.80 (0.67, 0.92)	0.85 (0.63, 0.94)	0.06	0.17	0.85 (0.72, 0.97)	0.87 (0.75, 0.93)	0.06	0.17
	Relaxation time (ms)	30.33 (28.06, 32.60)	0.89 (0.73, 0.96)	1.24	3.20	28.60 (25.82, 31.37)	0.87 (0.76, 0.93)	1.42	3.63
	Creep (D)	1.45 (1.24, 1.65)	0.89 (0.73, 0.96)	0.11	0.29	1.39 (−0.22, 3.00)	0.91 (0.83, 0.95)	0.82	2.28
Left side	Frequency (Hz)	10.84 (10.00, 11.67)	0.38 (−2.37, 0.47)	0.52	1.18	11.32 (10.49, 12.15)	0.73 (0.50, 0.85)	0.42	1.17
	Decrement	0.80 (0.69, 0.91)	0.85 (0.61, 0.94)	0.06	0.16	0.84 (0.69, 0.99)	0.76 (0.56, 0.87)	0.08	0.21
	Relaxation time (ms)	28.61 (24.48, 32.74)	0.59 (−0.04, 0.84)	2.38	5.83	26.89 (24.26, 29.51)	0.76 (0.56, 0.87)	1.34	3.71
	Creep (D)	1.38 (1.13, 1.62)	0.81 (0.53, 0.93)	0.14	0.30	1.31 (1.11, 1.50)	0.78 (0.60, 0.88)	0.10	0.27
Perineal (symptomatic cohort)		<i>n</i> = 14				<i>n</i> = 32			
Right side	Frequency (Hz)	11.95 (11.39, 12.50)	0.94 (0.80, 0.98)	0.28	0.79	11.80 (11.29, 12.30)	0.95 (0.89, 0.97)	0.26	0.72
	Decrement	1.05 (0.95, 1.13)	0.92 (0.76, 0.98)	0.05	0.12	0.99 (0.92, 1.06)	0.95 (0.90, 0.98)	0.04	0.10
	Relaxation time (ms)	26.02 (24.19, 27.85)	0.92 (0.74, 0.97)	0.88	2.58	27.09 (25.63, 28.55)	0.96 (0.92, 0.98)	0.75	2.07
	Creep (D)	1.36 (1.26, 1.46)	0.93 (0.80, 0.98)	0.05	0.14	1.42 (1.27, 1.56)	0.88 (0.76, 0.94)	0.07	0.21
Left side	Frequency (Hz)	12.41 (11.88, 12.94)	0.91 (0.72, 0.97)	0.25	0.75	12.34 (11.62, 13.06)	0.91 (0.81, 0.96)	0.37	1.02
	Decrement	1.08 (1.01, 1.15)	0.93 (0.78, 0.98)	0.03	0.10	1.03 (0.95, 1.11)	0.94 (0.87, 0.97)	0.04	0.12
	Relaxation time (ms)	23.92 (22.51, 25.32)	0.94 (0.82, 0.98)	0.69	1.98	25.23 (23.27, 27.18)	0.93 (0.86, 0.97)	1.00	2.77
	Creep (D)	1.27 (1.18, 1.35)	0.95 (0.86, 0.99)	0.04	0.11	1.33 (1.20, 1.46)	0.90 (0.80, 0.95)	0.07	0.18

ICC = intra-class correlation coefficient; SEM = standard error of measurement; MDC₉₅ = minimum detectable change at 95% CI.

reliability testing with any tool to ensure confidence in the accuracy of the measures obtained.

The properties of the thenar eminence were easier to measure, with no challenges encountered in measuring this easily located and accessible muscle. Assessing muscle stiffness in the smaller muscles of the body is difficult using traditional biomechanical measurements,²⁴ such as controlled stretch–release perturbations during quantified muscle contractions^{49,50} and controlled stretch forces,^{51,52} or using a hopping protocol, in which force and displacement are measured to provide a measure of stiffness of the lower limb as a whole.^{53,54} Therefore, alternative and innovative methods are required. The MyotonPRO is a small, portable, non-invasive device that now has established reliability to measure muscle stiffness in these difficult-to-access and small muscles.

The other muscle properties that the MyotonPRO measured (frequency, decrement, relaxation time, and creep) all showed good to very good reliability in both the thenar and perineal muscles, with the exception of two measures (frequency and relaxation time) performed by Assessor 2 on the left side in the perineal muscles of the asymptomatic cohort. Why only these two measures showed lower reliability compared with all other measures is unknown. The reliability of these measures might have been improved if the assessor's position had been midline—that is, approaching from the foot end of the bed rather than from the right side of the participant. Assessor 2 had more difficulty than Assessor 1 in positioning her body for measurement because of her size and the bed height. A future study may further investigate these measures and effects of assessor position.

The demonstrated good to very good interrater and intrarater reliability in measuring muscle stiffness using the MyotonPRO means that the device could be used as an objective reference standard in developing a digital palpation scale or as a pre- or post-intervention measurement device. Future research to develop a digital palpation scale would facilitate the accurate diagnosis of increased, reduced, or normal muscle stiffness, and it would assist with the clinical management of perineal muscle, and potentially levator ani muscle, dysfunction. Levator ani muscle dysfunction is implicated in many pelvic floor disorders in women, so the potential significance of this pilot work is substantial.

Although novel, our study has limitations. First, parity of the participants in the two cohorts may have conferred a small bias effect because only 26% of the participants had given birth. Because of the small number of participants in this parity group, sub-analysis of parity data was not warranted. A future, larger study might collect data on perineal or levator ani muscle obstetric trauma, which would allow sub-analysis of trauma versus non-trauma groups and provide further information on perineal muscle properties after vaginal birth. Also, because the participants were predominantly European–

Caucasian women (82%–87%), it was not possible to analyze ethnicity data; thus, the generalizability of these results is limited only to European–Caucasian women. Larger samples characterized by ethnic diversity are recommended for future studies to ascertain whether ethnicity is a factor in muscle stiffness.

CONCLUSION

Muscle stiffness of the smaller muscles of the body—specifically, the thenar eminence and perineal muscles—can be reliably and objectively measured using the MyotonPRO in women aged 18–50 years.

KEY MESSAGES

What is already known on this topic

The property of muscle stiffness of the thenar and perineal muscles has not been reported previously using objective and reliable devices because of the complexities of measurement and lack of suitable devices.

What this study adds

Objective and reliable measurements of thenar and perineal muscle stiffness were successfully obtained. This adds to the knowledge base regarding the muscle properties of small muscles of the body in women with and without vulvodynia.

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