

Reliability, Validity, and Precision of a Handheld Myometer for Assessing in Vivo Muscle Stiffness

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Biomechanically, muscle stiffness is the ratio of force response that results from and resists mechanical stretch.¹ The stiffness of the passive structures surrounding a joint contributes little to its biomechanical stability except at the end ranges of motion.² Research has found, however, that the active stiffness properties of muscles are essential to dynamic stability.^{3,4} Optimal levels of musculotendinous stiffness are highly correlated to significant increases in muscle performance.⁵ This increased muscle stiffness surrounding a joint could limit the translation suffered by the joint after an injurious perturbation.⁶ This in turn would limit strain on the ligamentous structures, ultimately decreasing the incidence and severity of injury. Excessive amounts of stiffness, such as the spasticity associated with cerebral palsy, can be detrimental, however. Therefore, the ability to accurately quantify active muscle stiffness in an attempt to identify the optimal level of stiffness is integral for both clinicians and researchers.

To date, methods for measuring active muscle stiffness have used complicated computer algorithms and sophisticated laboratory hardware, making accurate assessment of muscle stiffness nearly impossible for clinicians. The oscillatory method requires a sophisticated device to measure the frequency and decay of transient motion oscillations at the joint along with a complicated mathematical analysis to calculate the stiffness values. The passive force–position relationship, wherein joint-force responses are measured at different passive joint angles, requires a device that can accurately measure both joint position and force. In addition, in both examples, the outcome measurement is essentially overall joint stiffness, receiving contributions from the joint musculature, joint compression, and the passive structures surrounding the joint. There is a need for clinicians to be able to accurately measure the stiffness of individual muscles to isolate specific issues to be addressed in rehabilitation.

A handheld myometer is a device purported to accurately measure muscle stiffness in individual muscles. Previous research^{5,7–9} has shown that other methods of muscle-stiffness measurement (e.g., damped oscillatory and passive length–tension) are sensitive to levels of muscle force output. Sex differences have also been observed using these other measures of stiffness.^{7,10,11} Thus, we hypothesized that if a handheld myometer provides a valid assessment of stiffness that we would observe

similar patterns. Therefore, the purpose of this investigation was to examine the reliability and validity of a handheld myometer for assessing skeletal-muscle stiffness.

Methods

Subjects

20 subjects (6 men, 14 women; age 21.90 ± 2.93 y, height 170.46 ± 9.24 cm, mass 72.01 ± 11.47 kg) with no known neuromuscular disorders volunteered to participate in this study.

Instrumentation

All data were collected using the Myoton-3 (Müomeetria Ltd, Estonia, EU) handheld myometer (Figure 1). The tip of the myometer was placed on the tissue perpendicular to the underlying muscle. Slight pressure on the tip activated an electromagnet in the device, which exerted a local impact on the tissue by means of a brief mechanical impulse. This caused a minor deformation of the underlying muscle tissue. After the impact, the tip was quickly released, and the damped oscillatory behavior (Figure 2) of the tissue was recorded by an accelerometer in the device. The viscoelastic stiffness of the underlying tissue was calculated using the following equation¹²:

$$C = 4\pi^2 m^2 Y^2 + (\theta/4m)$$

where Y = the oscillation frequency, $Y = 1/T$ Hz, and θ is the logarithmic decrement of oscillation damping (Figure 2): $\theta = \ln(a_1/a_3)$.

Procedures

All testing was performed in the sports medicine research laboratory at the University of North Carolina at Chapel Hill. Each subject read and signed an informed-consent form approved by the institutional review board and was given the opportunity to ask questions if any arose.

After we recorded demographic data, subjects were positioned on a Biodex System 3 isokinetic dynamometer (Biodex Medical Systems, Shirley, NY) per the manufacturer's guidelines for knee extension (Figure 1). The dynamometer arm was locked with the subject's knee in 60° of flexion for isometric testing. Maximum voluntary isometric contraction (MVIC) values were calculated by averaging the peak force output of three 5-second maximal knee-extension contractions with 1 minute between exertions. Five consecutive myometric stiffness measurements were then



Figure 1 — Myoton-3 and subject positioning.

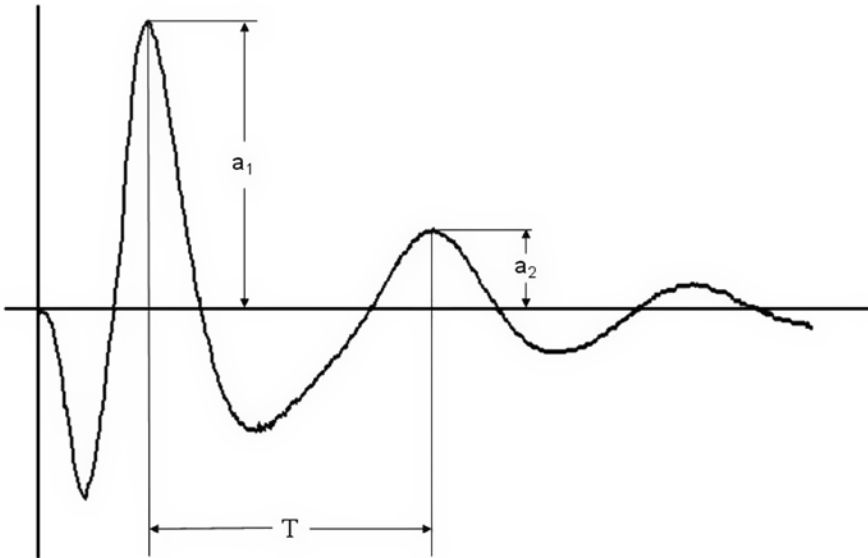


Figure 2 — Damped oscillatory behavior of the rectus femoris muscle (adapted from Vain and Kums¹²). T, time from peak 1 to peak 3; a_1 , amplitude peak 1; a_2 , amplitude peak 2.

collected in a randomized order from the midbelly of the rectus femoris muscle at each of 5 different activation levels: 10%, 20%, 30%, 40%, and 50% of the subject's MVIC. The subjects were given a 1-minute rest between testing conditions. A visual display of percentage MVIC was provided to the subjects as a reference for the graded contractions. They were permitted to practice until they felt comfortable sustaining the specific level of contraction before testing in each condition.

Statistical Analysis

Descriptive statistics were calculated for demographic information on age, height, and body mass. A mixed-model repeated-measures ANOVA was computed to assess rectus femoris viscoelastic-stiffness differences over the different load conditions and across sexes. Separate intraclass correlation coefficients ($ICC_{2,1}$) and standard errors of measurement (SEMs) were performed across the 5 trials in each load condition to assess trial-to-trial reliability and precision. All measurements were collected by the same investigator (SMZ) and were analyzed with the Statistical Package for the Social Sciences version 17.0 (SPSS, Chicago, IL).

Results

Mean stiffness values for each of the load conditions were consistent with previous literature (Table 1).¹³ Post hoc analysis revealed that stiffness values at 10% load were significantly different than those at 20%, 30%, 40%, and 50%

Table 1 Muscle Stiffness for the Individual Trials, N/m

% MVIC	Gender	Trial					Mean	SD	P	ICC _{2,1}	SEM
		1	2	3	4	5					
10%	men	410.50	374.50	389.50	386.33	395.00	391.17	74.96			
	women	276.07	278.79	280.64	282.57	290.29	281.67	30.76			
	total	316.40	307.50	313.30	313.70	321.70	314.52	69.11	.28	.92	23.34
20%	men	445.17	442.83	443.00	422.83	428.83	436.53	84.64			
	women	296.21	306.29	307.07	304.07	313.36	305.40	49.88			
	total	340.90	347.25	347.85	339.70	348.00	344.74	85.96	.41	.96	19.38
30%	men	461.00	461.83	463.50	441.50	457.33	457.03	89.34			
	women	313.50	323.14	314.29	334.14	323.14	321.64	73.58			
	total	357.75	364.75	359.05	366.35	363.40	362.26	99.28	.81	.94	26.69
40%	men	520.20	451.60	436.00	453.40	459.00	464.04	102.05			
	women	332.21	329.93	334.14	325.07	333.71	331.16	66.59			
	total	387.80	367.55	367.45	363.70	366.68	370.64	99.11	.35	.86	46.78
50%	men	514.83	485.17	545.17	508.00	506.83	512.00	127.86			
	women	330.36	334.07	328.93	340.71	331.57	333.13	67.56			
	total	385.70	379.40	393.80	390.90	384.15	386.79	120.40	.78	.91	38.00

MVIC, maximal voluntary isometric contraction.

loads and that 20% was significantly different than stiffness levels at 40% and 50% MVIC (Figure 3). Men generated significantly higher stiffness values than women at each level of contraction (Figure 4). There was also a significant load \times sex interaction that showed that the stiffness exhibited by men increased at a greater rate at the higher level of contraction than did that of women, especially at the 50% load level (Figure 4). Trial reliability and precision were excellent for each load condition, with ICCs ranging from .86 to .96 and SEMs ranging from 19.38 to 46.78 N/m (Table 1).

Discussion

Active muscle stiffness has been shown to be an integral component in decreasing injurious joint translations.^{3,4} It is therefore important to be able to easily and accurately quantify skeletal-muscle stiffness. Previously this has been difficult because of the specialized equipment and techniques needed, but the current investigation evaluated the reliability, validity, and precision of a handheld myometer, a user-friendly instrument, to quantify muscle stiffness.

Reliability Analysis

The current data show that the handheld myometer produced reliable and precise measurements of active muscle stiffness. It has been suggested that ICCs above .75 demonstrate good reliability, and those below .75 indicate moderate to poor reli-

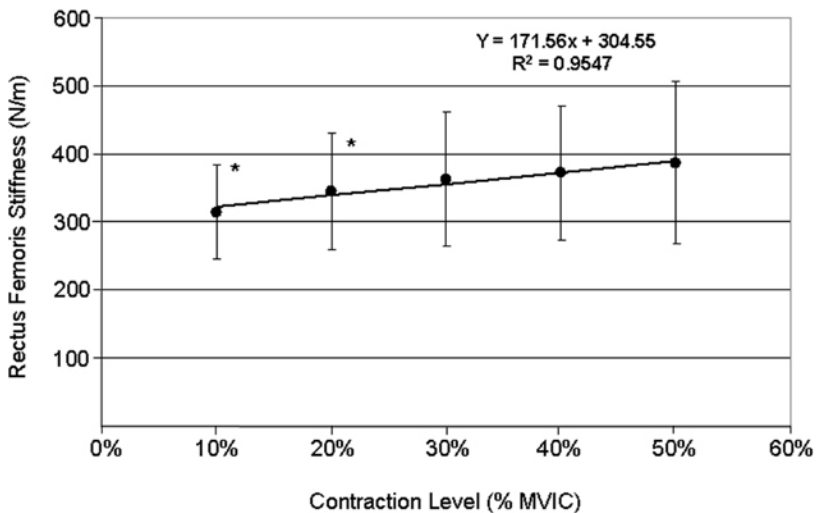


Figure 3 — Rectus femoris stiffness values across contraction levels. *10% < 20%, 30%, 40%, and 50%; 20% < 40% and 50%. MVIC, maximal voluntary isometric contraction.

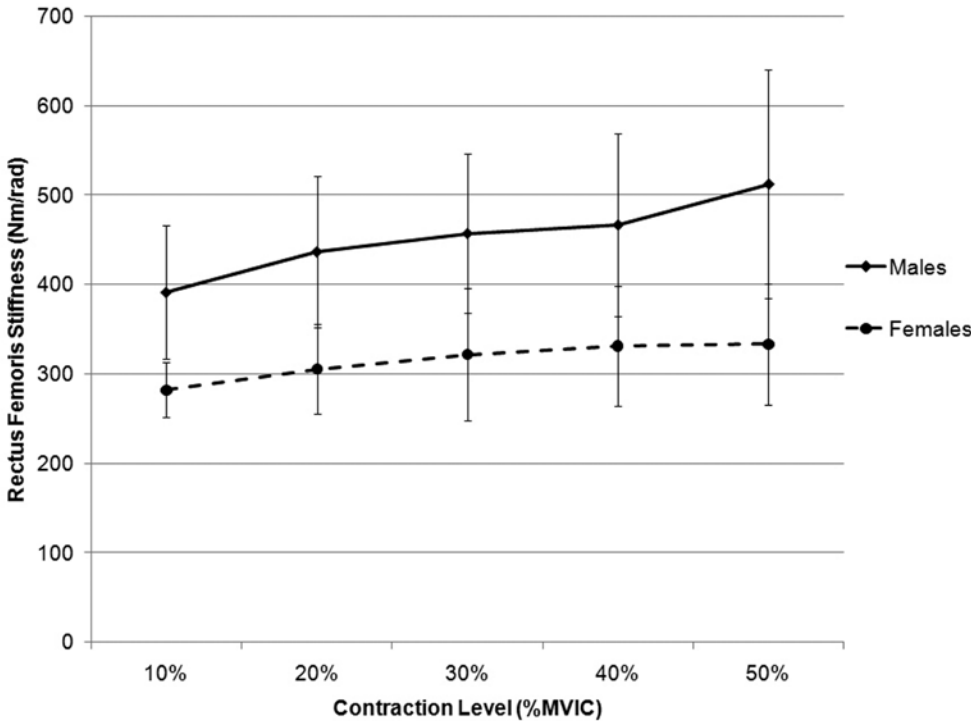


Figure 4 — Rectus femoris stiffness values across contraction levels and sex. *Men significantly greater at each contraction level.

ability.¹⁴ The very high ICCs in the current study (.86–.96 across the different load conditions) demonstrate that when the manufacturer’s recommended procedures are strictly followed, clinicians and researchers can obtain very consistent active muscle-stiffness measures across multiple trials. These values are comparable to reliability of other methods of stiffness calculation presented in the literature demonstrating ICCs ranging from .88 to .96.^{15,16}

The extremely low SEMs, ranging from 5.6% to 12.6% of the mean stiffness values, demonstrate excellent precision of the measurement when compared across trials. This is comparable to other methods presented in the literature that demonstrated SEMs ranging from 5.7% to 8.0% of the mean stiffness values.¹⁶ Although measures at all levels of submaximal voluntary contraction examined showed high reliability and excellent precision, the stiffness measures at 20% and 30% of MVIC produced the highest reliability and greatest precision, suggesting they may be the best choices for submaximal stiffness measurements.

Validity Analysis

Construct validity of the handheld myometer active muscle-stiffness measures was established by comparing the change in stiffness values relative to the change in

level of muscle contraction across sexes. Many studies on both in vitro^{9,17} and in vivo^{5,7,8} muscle tissue have demonstrated that active muscle stiffness is proportional to the level of muscle activation. In the current study active muscle-stiffness measures were collected at 10%, 20%, 30%, 40%, and 50% of the subjects' MVIC, causing a systematic increase in motor-unit recruitment as the level of contraction increased. Although not all the stiffness values were statistically different across contraction levels, the data trended toward a linear increase (R^2 of .95) in active stiffness levels with the increase in contraction level (Figure 3). This is consistent with previous research using the Myoton.¹³

It has also previously been demonstrated that males consistently have greater musculotendinous-stiffness values than females^{7,10,18} and that those differences widen as torque production in the underlying muscle increases.¹⁸ These results are mirrored in the current study, in which men had significantly greater stiffness values at each level of background contraction, with the greatest difference at the 50% MVIC load. The combination of the ability to detect increased stiffness values with a concomitant increase in background muscle activity and accurately portraying the stiffness characteristics across sexes suggest that the Myoton 3 is a valid instrument to measure viscoelastic-stiffness properties of the musculotendinous unit.

Another advantage of the Myoton over existing stiffness-measurement techniques is its ability to measure isolated muscles. With the standard oscillatory technique of assessing muscle stiffness it is nearly impossible to isolate specific muscles and avoid cocontraction of antagonist musculature. Cocontraction has been shown to be a significant contributor to joint stiffness,^{11,19} so the Myoton may allow for a more specific measure of isolated muscle stiffness than currently used techniques for stiffness assessment. This could be an invaluable tool for clinicians to isolate specific muscles to evaluate their individual contributions to joint stability.

Limitations

There are a few limitations and weaknesses to the current study. Most notably, only 1 aspect of validity, construct validity, was examined. There is no gold standard of stiffness measurement in the literature, making comparisons to an accepted standard difficult. Any of the previously used measures of stiffness use effective stiffness measures that include contributions from all the surrounding musculature, passive joint structures, joint compression, and so on. No other measurement technique we are aware of allows for in vivo stiffness measures of individual muscles. There were also unequal numbers of subjects in the gender groups. There was still adequate statistical power to elucidate group differences, but future investigations should place greater emphasis on similarity in sample size. Also, future studies should examine other aspects of reliability, such as intratester and day-to-day reliability of the measure, to get a more complete picture of the myometer's reliability.

Conclusions

The results of this study suggest that a handheld myometer may be an effective clinical measure of active muscle stiffness. The valid, reliable, and precise measurements it collects combined with its ease of use and ability to measure active muscle stiffness in specific, individual muscles make it a valuable tool to any

practitioner or researcher interested in in vivo biomechanical properties of skeletal muscle. Although myometry may not completely replace the computer algorithms and sophisticated hardware needed in many applications, this simple device shows promise as a tool in many research laboratories and therapy clinics.

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