MEDICAL SCIENCE MONITOR

DIAGNOSTIC TECHNIQUES

e-ISSN 1643-3750
© Med Sci Monit, 2018; 24: 4876-4881
DOI: 10.12659/MSM.909531

Received: 2018.02.17
Accepted: 2018.03.12
Published: 2018.07.14

Quantifying the Stiffness of Achilles Tendon: Intra- and Inter-Operator Reliability and the Effect of Ankle Joint Motion

Authors' Contribution:
Study Design A
Data Collection B
Statistical Analysis C
Data Interpretation D
Manuscript Preparation E
Literature Search F
Funds Collection G

ACE 1 Chun Long Liu
BCD 2 Ya Peng Li
ABD 3 Xue Qiang Wang
ACF 2 Zhi Jie Zhang

1 Clinical Medical College of Acupuncture, Moxibustion and Rehabilitation, Guangzhou University of Chinese Medicine, Guangzhou, Guangdong, P.R. China
2 Rehabilitation Therapy Center, Henan Province Orthopedic Hospital, Luoyang, Henan, P.R. China
3 Department of Sport Rehabilitation, Shanghai University of Sport, Shanghai, P.R. China

Corresponding Author: Zhi Jie Zhang, e-mail: Sportspt@163.com
Source of support: This study was supported by Project of Science Research of Traditional Chinese Medicine of Henan Province of China (2017ZY1004)

Background: The objectives of the present study were to examine the intra- and inter-operator reliability of the MyotonPRO device in quantifying the stiffness of the Achilles tendon and the device's ability to examine the modulation in stiffness of the Achilles tendon during ankle joint flexion.

Material/Methods: Twenty asymptomatic participants (10 males and 10 females; mean age: 25.0±3.1 years) were recruited for this study. The stiffness of the Achilles tendon was quantified using the MyotonPRO device.

Results: The results revealed excellent intra- and inter-operator reliability for quantifying Achilles tendon stiffness with the ankle joint in a neutral position and detected a 13.9% increase in stiffness of the Achilles tendon between 0° and 30° of ankle joint flexion. The minimal detectable change (MDC) in tendon stiffness was 45 Newton/meter (N/m).

Conclusions: Our findings indicated that the MyotonPRO device is a feasible method to quantify the stiffness of the Achilles tendon and monitor its changes. Thus, it is an essential tool to use to examine the modulation in the stiffness of the Achilles tendon due to pathology or interventions for future studies.

MeSH Keywords: Achilles Tendon • Ankle Joint • Elastic Tissue

Full-text PDF: https://www.medscimonit.com/abstract/index/idArt/909531

2243 1 3 26

Indexed in: [Current Contents/Clinical Medicine] [SCI Expanded] [ISI Alerting System] [ISI Journals Master List] [Index Medicus/MEDLINE] [EMBASE/Excerpta Medica] [Chemical Abstracts/CAS]

Background

Tendons, as a mechanical buffer, are mainly responsible for transmitting and absorbing force during jumping and landing. They play an important role in storing and releasing energy and allowing muscles to work more efficiently. Changes in tendon stiffness (whether acute or chronic) may have a direct effect on functional performance [1]. Thus, the ability to quantify tendon properties in a quick and reliable manner may prove to be a useful addition to the battery of tests normally applied to assess skeletal muscle function.

Elastography ultrasound has been used to quantify viscoelastic properties of various tendons, including supraspinatus, patellar, and Achilles tendons. One study demonstrated that it is a reliable tool for the measurement of Achilles tendon elastic properties in healthy participants [2]. In addition, elastography ultrasound has been used to compare differences in healthy and pathological Achilles tendon properties [3–5]. Our recent study revealed that pain and functional disability associated with patellar tendinopathy was related to the viscoelastic properties of the patellar tendon [6]. Although elastography ultrasound is an excellent tool for quantifying tissue properties, the equipment costs and required technical expertise limit wider clinical use.

Portable devices for quantifying mechanical properties of tissue are less expensive and can be used routinely in the clinic. The MyotonPRO is a commercially available hand-held device that can be used to quantify viscoelastic properties (i.e., tone, elasticity, and stiffness) of skeletal muscle, fascia, and tendon. Much of the published work is based on earlier prototypes including Myoton-2 and Myoton-3 [7]. Data based on the newest model, MyotonPRO, has also been published [8,9], including data on changes in muscle viscoelastic properties associated with aging [10–12] and pathological conditions such as stroke [13]. MyotonPRO measurements of muscle tone, stiffness, and elasticity were found to be greater in the upper trapezius and sternocleidomastoid of older women compared to younger women [12]. Lumbar fascia stiffness measured by the MyotonPRO was greater in the right side than the left side, and greater in men than in women [9]. Intra- and inter-operator reliability of MyotonPRO measurements of biceps brachii tone, stiffness, and elasticity was generally good in healthy adults, although less so in patients with paratonia, a form of hypertonia [14].

Few studies have used the MyotonPRO to study tendon properties [15,16]. In one report, the MyotonPRO was found to be a feasible tool for quantifying acute changes in muscle and Achilles tendon elastic properties when participants were placed in a microgravity environment [16]. Another study reported that the MyotonPRO can detect acute changes in Achilles tendon stiffness as a result of bouts of karate sparring [15]. To the authors' knowledge, no studies have examined the reliability and precision of the MyotonPRO measurements of Achilles tendon elastic properties, and no studies have used the MyotonPRO to examine modulation in the stiffness of Achilles tendon during ankle joint motion.

The objectives of this study were 1) to determine the intra- and inter-operator reliability of quantifying the stiffness of the Achilles tendon and to examine the minimal detectable change (MDC), and 2) to determine the modulation in the stiffness of Achilles tendon during ankle joint motion.

Material and Methods

Ethics statement

This study was approved by the Human Subjects Ethics Committee of the Clinical Medical College of Acupuncture, Moxibustion, and Rehabilitation, Guangzhou University of Chinese Medicine. All participants provided signed, written informed consent prior to involvement in the experiment.

Participants

Twenty asymptomatic participants (10 females and 10 males, aged 25.0±3.1 years) were included in this study. Their mean height, weight, and body mass index (BMI) were 168.1±7.2 cm, 66.1±15.1 kg, and 23.2±4.2 kg/m^2, respectively. They were recruited from the hospital medical staff and students in the Department of Physical Therapy. Participants were included if they were older than 18 years of age and had no history of Achilles tendon pain, trauma, or surgery. The dominant leg was defined as the leg used for kicking a ball [17,18].

Equipment

The stiffness of the Achilles tendon was quantified by a portable MyotonPRO (Muomeetria Ltd., Tallinn, Estonia). The MyotonPRO measures mechanical oscillations of soft tissues induced by a mechanical impulse. A brief mechanical impulse was applied, followed by a quick release, to the skin overlying the muscle. The MyotonPRO device provides the stiffness value (Newton/meter; N/m) that reflects the resistance of the soft tissue to force deforming the soft tissue. The stiffness value is calculated as maximum acceleration of oscillation/maximum displacement of the tissue. A larger index indicates a stiffer tendon.

Indexed in: [Current Contents/Clinical Medicine] [SCI Expanded] [ISI Alerting System] [ISI Journals Master List] [Index Medicus/MEDLINE] [EMBASE/Excerpta Medica] [Chemical Abstracts/CAS]

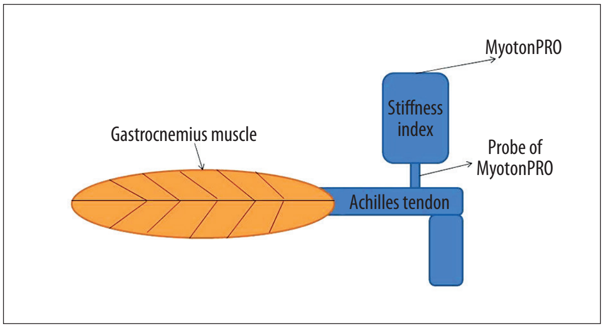

Figure 1. Schematic of stiffness measurement of Achilles tendon using a portable MyotonPRO device.

Measurement of Achilles tendon stiffness

The participants were in a prone position on an examination bed, with the hip and knee fully extended and the ankle joint in a resting position. The calcaneal tuberosity was palpated and marked by a physical therapist. The measurement site for tendon properties was 4 cm above the calcaneal tuberosity, because tendon pathologies commonly occur in this area [19,20]. The measurement site was marked by a pen and the MyotonPRO was placed at this site so that the probe was perpendicular to the Achilles tendon (Figure 1). The multiscan modes were applied and recorded including 10 impulses, 1-second apart. The stiffness of the Achilles tendon was quantified at 0° and 30° of ankle joint dorsiflexion, respectively. The angle of the ankle joint was measured using a plastic goniometer. The ankle joint at 0° and 30° of flexion was kept using a self-made splint.

For the intra-operator reliability, each participant was evaluated by the rater ZZJ (physical therapist) according to the aforementioned protocol. After a 5-day interval, the same participant was reassessed by the rater ZZJ. For the inter-rater reliability test, each participant was quantified by both raters (ZZJ and LCL) once, with 30 minutes between the measurements on the same day. Both raters were blinded to the results after testing. Two operators were trained in using the device and received a formal training course. The mean of 3 measurements was used in the study.

Statistical analyses

Commercial software (SPSS version 17.0, SPSS Inc. Chicago, IL, USA) was used for statistical analysis. Normality distribution was assessed using the Shapiro-Wilk test. Descriptive statistics were used to calculate participant demographic characteristics such as age, body weight, and height. The intra- and inter-operator reliability was computed using intra-class correlation coefficient (ICC). The intra-operator (measurements taken on 2 occasions separated by 5 days) and inter-operator (measurements by 2 operators) reliability of the measurement of tendon stiffness was examined using ICC (3,1) and ICC (2,2). The coefficient of variance (CV=standard deviation/mean×100%] was computed. The standard error measurement (SEM) was calculated based on the following formula: SEM=standard deviation×√1-ICC). The MDC was computed using the following formula: MDC=1.96×SEM×√2. Bland and Altman plots were used to assess intra-operator reliability and between 2 operators (inter-operator) to provide a visual presentation of the degree of agreement and to identify bias and outliners. A paired *t*-test was used to compare mean stiffness index of the Achilles tendon between 0° and 30° of dorsiflexion of the ankle joint. The level of significance was set at *P*=0.05, and data are presented as mean ±SD.

Results

Intra- and inter-operator reliability

Both intra- and inter-operator reliability of measuring tendon stiffness bilaterally was good, with ICC above 0.87, SEM less than 19 N/m, MDC less than 45 N/m, and CV less than 11% (Table 1). Bland and Altman plots for intra-operator reliability

Table 1. The intra and inter-operator reliability of MyotonPRO in measurement of Achilles tendon stiffness.

	Intra-operator reliability						Inter-operator reliability					
	Test1 (Mean ±SD)	Test2 (Mean ±SD)	SEM	ICC	95%CI	MDC	Operator I (Mean ±SD)	Operator II (Mean ±SD)	SEM	ICC	95%CI	MDC
Dominant leg	776.11 ±71.70	769.83 ±78.00	16.03	0.90	0.76–0.96	44.44	776.11 ±71.70	777.47 ±81.59	18.24	0.95	0.86–0.98	44.44
Non-dominant leg	786.08 ±59.11	778.08 ±75.47	13.22	0.88	0.71–0.95	36.64	786.08 ±59.11	770.93 ±61.51	13.75	0.88	0.70–0.95	36.64

SD – standard deviation; SEM – standard error mean; ICC – intraclass correlation coefficient; MDC – minimum detectable change; 95%CI – 95% confidence interval.

Indexed in: [Current Contents/Clinical Medicine] [SCI Expanded] [ISI Alerting System] [ISI Journals Master List] [Index Medicus/MEDLINE] [EMBASE/Excerpta Medica] [Chemical Abstracts/CAS]

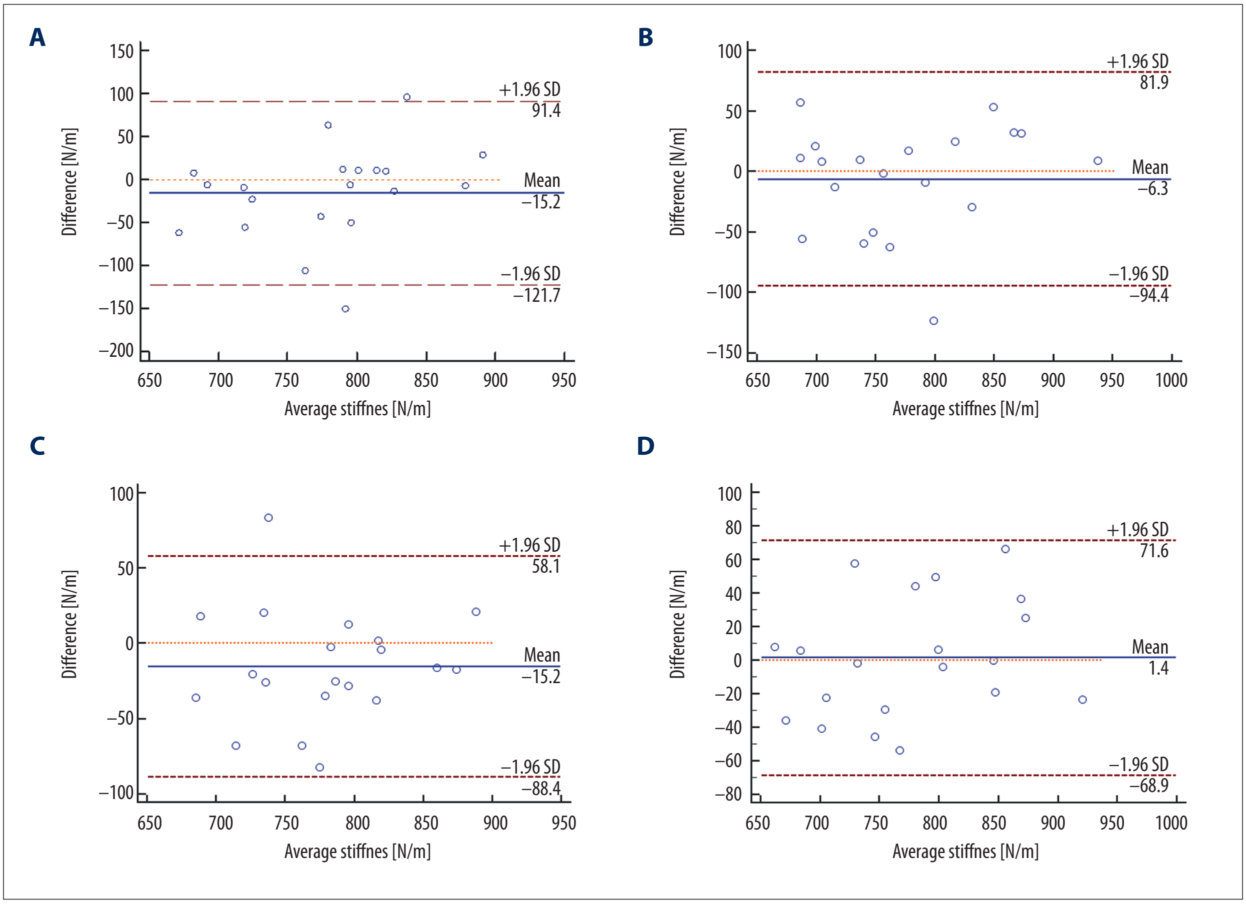

Figure 2. Bland and Altman plots of intra- and inter-operator reliability of tendon stiffness. The difference in tendon stiffness between day 1 and day 5 is plotted against mean tendon stiffness (average of the 2 days for operator 1) for each participant in the dominate leg (**A**) and non-dominate leg (**B**). The difference in tendon stiffness between operator 1 and operator 2 is plotted against mean tendon stiffness (average of the 2 operators) for each participant in the dominate leg (**C**) and non-dominate leg (**D**). In each panel, the continuous line is the mean difference and the dotted lines represent 2 SD above and below the mean difference.

in the dominant and non-dominate leg are presented in Figure 2A, 2B, and corresponding data for inter-observer reliability are shown in Figure 2C, 2D. For intra-operator reliability, the mean difference was –15.2 or –6.3 N/m and the 95% limits of agreement were –121.7 to 91.4 or –94.4 to 81.9 N/m. For inter-observer reliability the mean difference was –15.2 or 1.4 N/m and the 95% limits of agreement were –88.4 to 58.1 or –68.9 to 71.6 N/m.

Changes in the stiffness of the Achilles tendon

The stiffness index of Achilles tendon was 1143 N/m at 0 flex of ankle joint, and 1329 N/m when ankle joint was flexed to 10 (P=0.002) (Figure 3). These results indicated that the MyotonPRO device can be used to examine the modulation in the stiffness of Achilles tendon at 0° and 30° of ankle joint dorsiflexion.

Discussion

Overall, the present study supports the intra- and inter-operator reliability of measuring Achilles tendon stiffness in healthy participants using a portable MyotonPRO device. We found excellent intra- and inter-operator reliability in using the MyotonPRO device to quantify the stiffness of the Achilles tendon. The precision of the measurements was revealed using relatively low SEM and MDC values. A significant increase in the stiffness index of the Achilles tendon at 30° of the ankle joint dorsiflexion was found when compared to the ankle joint at 0 of ankle joint dorsiflexion.

Intra- and inter-operator reliability

The MyotonPRO device is a recently developed technique to quantify the stiffness of the Achilles tendon [15,16]. To our knowledge, the present study is the first study to investigate

Indexed in: [Current Contents/Clinical Medicine] [SCI Expanded] [ISI Alerting System] [ISI Journals Master List] [Index Medicus/MEDLINE] [EMBASE/Excerpta Medica] [Chemical Abstracts/CAS]

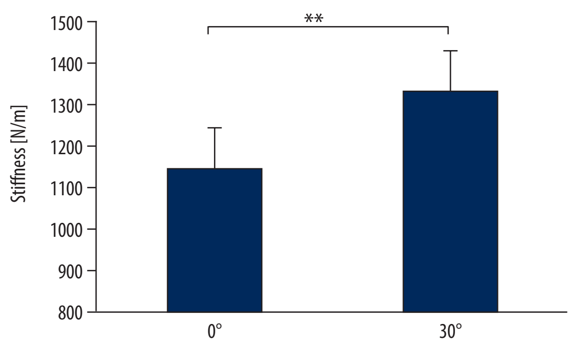

Figure 3. Comparisons of the stiffness index of the Achilles tendon between 0° and 30° of ankle joint dorsiflexion.

the intra- and inter-operator reliability of assessing the stiffness of the Achilles tendon. Our results revealed excellent intra- and inter-operator reliability in measuring the stiffness of the Achilles tendon using a portable MyotonPRO device. All the other reported studies only examined the reliability of assessing the stiffness of skeletal muscles using a portable MyotonPRO device. Our results are consistent with previous studies focused on skeletal muscles. In a study by Chuang et al. [21], the stiffness of biceps muscles was quantified using the Myoton-3 Myometer. They found good intra-operator reliability ranged from 0.79 to 0.96, corresponding to SEM of 8.8 N/m and MDC of 20.5 N/m. However, inter-operator reliability was not examined in their study. One study by Lidström et al. [22] examined the test-retest reliability of Myotonometer to quantify the stiffness of the rectus femoris among study participants with cerebral palsy. They revealed that ICC values ranged from 0.40 to 0.87. Leonard et al. [23] examined the intra-and inter-operator reliability of Myotonometer for measurement of the stiffness of the biceps muscles. They found that ICC values ranged from 0.85 to 0.95. The findings from our study established excellent repeatability for using MyotonPRO to measure the stiffness of the Achilles tendon and supported our primary hypothesis that MyotonPRO measurements of stiffness of the Achilles tendon is applicable for use in the research and clinical settings.

The elastic properties may be regarded as biomarkers to assess functional capacities of the tendon and to monitor the efficacy of treatment and make a better treatment plan for return to play and work. Therefore, a number of researchers have attempted to investigate the elastic properties of the tendon, using different methods such as ultrasonography combined with electromyography (EMG) and supersonic shear wave imaging (SSI). Ultrasonography with EMG was used to assess the elastic properties of the human Achilles tendon. This method was based on the tendon-aponeurosis elongation during maximal voluntary contraction [24,25]. However, this technique has some limitations such as complex procedures (ultrasound probe fixation), time consumption, complicate data analysis post-testing, and dependence on the muscle contraction [26]. More recently, elastography ultrasound was used to assess the elastic properties of tendons such as the Achilles tendon [3] and the patellar tendon [6]. However, the elastography ultrasound machine is relative expensive and is not always available in the clinical settings.

In addition, our study also calculated the MDC that could provide a value to reflect a true change as a reference for further study. In terms of our findings, measurements of the Achilles tendon stiffness should be greater than 45 N/m to reflect real change.

Modulation in stiffness index of Achilles tendon

In the present study, our findings revealed that the stiffness index of the Achilles tendon quantified at 0° was 1143 N/m and increased to 1329 N/m at 30° of ankle joint dorsiflexion. The change in stiffness were greater than MDC (45 N/m), indicating true change. The results of the present study also revealed an increase of 13.9% in the stiffness of the Achilles tendon from 0° to 30° of ankle joint dorsiflexion. These results obtained using the MyotonPRO device were consistent with those reported in previous investigations based on shear wave elastography ultrasound. For example, when the stiffness of the Achilles tendon was quantified using shear wave elastography ultrasound, an increase of 62.8% in the stiffness of Achilles tendon when the ankle joint was dorsiflexed to 30° was also found.

Based on the current study, we recommend using the mean stiffness index quantified by the same operator to delineate the stiffness of the Achilles tendon. The mean index of 1143 N/m at 0° and 1329 N/m at 30° should be considered a reference for future studies. The point 4 cm above the calcaneal tuberosity was selected for measuring the stiffness of the Achilles tendon, as tendon pathologies commonly occur in this area [19,20].

Limitations

There are some limitations in the current study. Only the stiffness of part of the Achilles tendon was evaluated; and healthy participants were recruited for the study. Future studies should investigate the changes of the Achilles tendon stiffness among participants with Achilles tendon disorders such as Achilles tendinopathy.

Indexed in: [Current Contents/Clinical Medicine] [SCI Expanded] [ISI Alerting System] [ISI Journals Master List] [Index Medicus/MEDLINE] [EMBASE/Excerpta Medica] [Chemical Abstracts/CAS]

Conclusions

The present study demonstrated the MyotonPRO device is a reliable tool to quantify the stiffness of the Achilles tendon. Furthermore, modulation greater than 45 N/m can be considered as a true change. This technique was sensitive for assessing the modulation in the Achilles tendon stiffness during ankle joint dorsiflexion.

Acknowledgement

Thanks are due to Dr. Liu for assistance with the experiments and to Dr. Fang for valuable discussion.

Conflict of interests

The authors declare that they have no competing interests.

References:

1. Silver FH, Freeman JW, Seehra GP: Collagen self-assembly and the development of tendon mechanical properties. J Biomech, 2003; 36: 1529–53
2. Drakonaki EE, Allen GM, Wilson DJ: Real-time ultrasound elastography of the normal Achilles tendon: Reproducibility and pattern description. Clin Radiol, 2009; 64: 1196–202
3. Chen XM, Cui LG, He P et al: Shear wave elastographic characterization of normal and torn achilles tendons: A pilot study. J Ultrasound Med, 2013; 32: 449–55
4. Sconfienza LM, Silvestri E, Cimmino MA: Sonoelastography in the evaluation of painful Achilles tendon in amateur athletes. Clin Exp Rheumatol, 2010; 28: 373–78
5. Tan S, Kudaş S, Özcan AS et al: Real-time sonoelastography of the Achilles tendon: Pattern description in healthy subjects and patients with surgically repaired complete ruptures. Skeletal Radiol, 2012; 41: 1067–72
6. Zhang ZJ, Ng GY, Lee WC, Fu SN: Changes in morphological and elastic properties of patellar tendon in athletes with unilateral patellar tendinopathy and their relationships with pain and functional disability. PLoS One, 2014; 9: e108337
7. Bizzini M, Mannion AF: Reliability of a new, hand-held device for assessing skeletal muscle stiffness. Clin Biomech (Bristol, Avon), 2003; 18: 459–61
8. Gervasi M, Sisti D, Amatori S et al: Muscular viscoelastic characteristics of athletes participating in the European Master Indoor Athletics Championship. Eur J Appl Physiol, 2017; 117: 1739–46
9. Nair K, Masi AT, Andonian BJ et al: Stiffness of resting lumbar myofascia in healthy young subjects quantified using a handheld myotonometer and concurrently with surface electromyography monitoring. J Bodyw Mov Ther, 2016; 20: 388–96
10. Agyapong-Badu S, Warner M, Samuel D, Stokes M: Measurement of ageing effects on muscle tone and mechanical properties of rectus femoris and biceps brachii in healthy males and females using a novel hand-held myometric device. Arch Gerontol Geriatr, 2016; 62: 59–67
11. Aird L, Samuel D, Stokes M: Quadriceps muscle tone, elasticity and stiffness in older males: Reliability and symmetry using the MyotonPRO. Arch Gerontol Geriatr, 2012; 55: e31–39
12. Kocur P, Grzeskowiak M, Wiernicka M et al: Effects of aging on mechanical properties of sternocleidomastoid and trapezius muscles during transition from lying to sitting position-A cross-sectional study. Arch Gerontol Geriatr, 2017; 70: 14–18
13. Fröhlich-Zwahlen AK, Casartelli NC, Item-Glatthorn JF, Maffiuletti NA: Validity of resting myotonometric assessment of lower extremity muscles in chronic stroke patients with limited hypertonia: A preliminary study. J Electromyogr Kinesiol, 2014; 24: 762–69
14. Van Deun B, Hobbelen JS, Cagnie B et al: Reproducible measurements of muscle characteristics using the MyotonPRO device: Comparison between individuals with and without paratonia. J Geriatr Phys Ther, 2016 [Epub ahead of print]
15. Pożarowszczyk B, Pawlaczyk W, Smoter M et al: Effects of karate fights on Achilles tendon stiffness measured by Myotonometry. J Hum Kinet, 2017; 56: 93–97
16. Schneider S, Peipsi A, Stokes M et al: Feasibility of monitoring muscle health in microgravity environments using Myoton technology. Med Biol Eng Comput, 2015; 53: 57–66
17. Guette M, Gondin J, Martin A: Time-of-day effect on the torque and neuromuscular properties of dominant and non-dominant quadriceps femoris. Chronobiol Int, 2005; 22: 541–58
18. Bjornaraa J, Di Fabio RP: Knee kinematics following ACL reconstruction in females; The effect of vision on performance during a cutting task. Int J Sports Phys Ther, 2011; 6: 271–84
19. Peltonen J, Cronin NJ, Avela J, Finni T: *In vivo* mechanical response of human Achilles tendon to a single bout of hopping exercise. J Exp Biol, 2010; 213: 1259–65
20. Stenroth L, Peltonen J, Cronin NJ et al: Age-related differences in Achilles tendon properties and triceps surae muscle architecture *in vivo*. J Appl Physiol (1985), 2012; 113: 1537–44
21. Chuang LL, Wu CY, Lin KC, Lur SY: Quantitative mechanical properties of the relaxed biceps and triceps brachii muscles in patients with subacute stroke: A reliability study of the myoton-3 myometer. Stroke Res Treat, 2012; 2012: 617694
22. Lidström A, Ahlsten G, Hirchfeld H, Norrlin S: Intrarater and interrater reliability of Myotonometer measurements of muscle tone in children. J Child Neurol, 2009; 24: 267–74
23. Leonard CT, Deshner WP, Romo JW et al: Myotonometer intra- and interrater reliabilities. Arch Phys Med Rehabil, 2003; 84: 928–32
24. Hansen P, Aagaard P, Kjaer M, Larsson B, Magnusson SP. Effect of habitual running on human Achilles tendon load-deformation properties and cross-sectional area. J Appl Physiol (1985), 2003; 95: 2375–80
25. Bohm S, Mersmann F, Marzilger R et al: Asymmetry of Achilles tendon mechanical and morphological properties between both legs. Scand J Med Sci Sports, 2015; 25: e124–32
26. Hansen P, Bojsen-Moller J, Aagaard P et al: Mechanical properties of the human patellar tendon, *in vivo*. Clin Biomech (Bristol, Avon), 2006; 21: 54–58

Indexed in: [Current Contents/Clinical Medicine] [SCI Expanded] [ISI Alerting System] [ISI Journals Master List] [Index Medicus/MEDLINE] [EMBASE/Excerpta Medica] [Chemical Abstracts/CAS]