Relationship Between Achilles Tendon Stiffness Using Myoton PRO and Translation Using a Tensile Testing Machine: A Biomechanical Study of a Porcine Model

Wataru Kurashina [1, 2] , Tsuneari Takahashi [3] , Hideyuki Sasanuma [4] , Akihiro Saitsu [4] , Katsushi Takeshita [4]

1. Graduate School of Medicine, Jichi Medical University, Shimotsuke, JPN 2. Department of Rehabilitation, Tochigi Medical Center Shimotsuga, Tochigi, JPN 3. Department of Orthopaedic Surgery, Ishibashi General Hospital, Shimotsuke, JPN 4. Department of Orthopaedics, Jichi Medical University, Shimotsuke, JPN

Corresponding author: Tsuneari Takahashi, tsuneari9@jichi.ac.jp

Abstract

Background

Achilles tendinopathy is a common ankle disorder in both the general population and athletes. This condition can alter the mechanical characteristics of the Achilles tendon (AT) by decreasing tendon stiffness. Achilles tendinopathy is primarily treated conservatively; however, few monitoring tools exist for evaluating the condition of the AT. The Myoton PRO (Myoton AS, Tallinn, Estonia) device is a handheld tool used to evaluate tissue stiffness. However, no basic studies have examined the validity of Myoton PRO for assessing the AT. This study aimed to assess the validity of Myoton PRO using animal ATs and to examine its clinical applicability.

Methods

We used 28 fresh porcine ankles and evaluated AT stiffness at the calcaneus insertion site (AT0) and 2.0 cm above the calcaneus (AT2) using Myoton PRO. We also measured changes in the AT length using a tensile testing machine during the cyclic loading test. We investigated the correlation between dynamic stiffness and length change. Furthermore, we assessed the difference in stiffness between AT0 and AT2.

Results

The dynamic stiffness was 717.6 ± 183.1 N/m at AT0 and 467.4 ± 152.3 N/m at AT2. The change in length during the cyclic loading test was 1.8 ± 0.7 mm. The correlation between dynamic stiffness and length change was as follows: AT0, r=-0.61; AT2, r=-0.64 (P<0.001). The dynamic stiffness at AT0 was significantly greater than that at AT2 (P<0.001).

Conclusions

AT assessment using Myoton PRO has potential clinical utility as an indicator of tissue stiffness.

Introduction

Achilles tendinopathy is a common ankle disorder in both the general population and athletes [1]. Achilles tendinopathy is frequently observed in adults, with an incidence rate of 2.35 per 1,000. Notably, a relationship with sports activity has been recorded in 35% of the cases [2]. Achilles tendon (AT) injuries can be categorized based on the location of pain: insertional tendinopathy (20%-25%), midportion tendinopathy (55%-65%), and proximal musculotendinous junction (9%-25%) injuries [3].

Achilles tendinopathy is clinically diagnosed when patients present with a combination of localized pain, swelling of the AT, and loss of function [3,4]. Both subjective and objective orthopedic clinical tests have demonstrated significant diagnostic accuracy and capability for Achilles tendinopathy [5]. Imaging examinations, including magnetic resonance imaging (MRI) and ultrasound, have been used to rule out other injuries and provide additional clinical information [6,7]. Achilles tendinopathy can alter the mechanical, material, and morphological properties of the tendon structure, resulting in a decrease in stiffness and Young's modulus, along with an increase in tendon cross-sectional area and diameter [8,9]. Achilles tendinopathy is primarily treated conservatively, often through exercise therapy [10,11]. However, few optimal monitoring tools exist for evaluating the condition of the AT [12,13].

In recent years, the evaluation of AT stiffness using ultrasound elastography has become a valuable method

[14]. However, the disadvantages of ultrasound elastography include differences in device performance and high cost, which make it difficult to use in clinical settings [15]. Another tool for evaluating stiffness, the Myoton PRO, correlates well with ultrasound elastography [16,17]. The Myoton PRO device is a handheld tool that can be used to evaluate tissue stiffness; however, no basic studies have examined its validity for assessing the AT. This study aimed to verify the validity of Myoton PRO using animal ATs and to examine its clinical applicability. We hypothesized that Myoton PRO correlates with a classical tensile testing machine.

Materials And Methods

Study design

Animal experiments were conducted in our institution's biomechanics laboratory in accordance with the regulations of the Animal Care and Use Committee. The need for ethical approval from the committee was waived owing to the ex vivo nature of this study. We used porcine AT because of previous reports showing great similarities between pigs and humans in body weight, anatomy, histology, and immunology [18]. This study used 28 fresh porcine ankles (mean weight: 43.5 ± 4.2 kg; range: 38.1-51.6 kg). The tibia, fibula, talus, navicular, and cuboid bone were cut off, and the gastrocnemius and soleus muscles attached to the AT were carefully removed. Sutures were then placed proximal to the AT. The calcaneus was inserted into aluminum tubes with cement [19-20].

Dynamic stiffness using Myoton PRO

Myoton PRO (Myoton AS, Tallinn, Estonia) is a handheld device that generates a mechanical impulse on the skin overlying a target structure [9] (Figure *1*). The measurement method employed by Myoton PRO involves a mechanical impact released under constant prepressure (0.18 N) on the subcutaneous panniculus above the measured muscle or tendon. The oscillation of the tissue under the probe enables the calculation of the viscoelastic properties of the tissue. One parameter is dynamic stiffness, which is used to identify tissue characteristics [21]. This parameter can be calculated as the maximum acceleration of the oscillation and deformation of the tissue detected by the transducer (N/m) [22]. We evaluated AT stiffness at the calcaneus insertion site (AT0) and 2.0 cm above the calcaneus (AT2) using Myoton PRO. We obtained the average value of three measurements and assessed the intraobserver reliability using Myoton PRO.

2023 Kurashina et al. Cureus 15(11): e49359. DOI 10.7759/cureus.49359

2 of 9

FIGURE 1: Photograph of the Myoton PRO device

Biomechanical testing using a tensile testing machine

The prepared AT-calcaneus composite specimens were mounted on a tensile testing machine (Tensilon RTG 1250; Orientec Co., Tokyo, Japan) using specially designed grips (Figure 2). A saline solution was used to keep the structures moist during the experiment. Before testing, a static preload of 5 N was applied to the specimen, and then we evaluated the AT0 and AT2 stiffness using Myoton PRO (Figure 3). This assessment was followed by subjecting the specimen to 20 cycles of cyclic loading, ranging from 0 to 40 N, at a crosshead speed of 100 mm/min. This cyclic loading test was performed by applying tensile loading to the AT parallel to its long axis. The change in length during the cyclic loading was recorded. These conditions have been frequently used for measurements in previous studies using large-animal models [19-20].
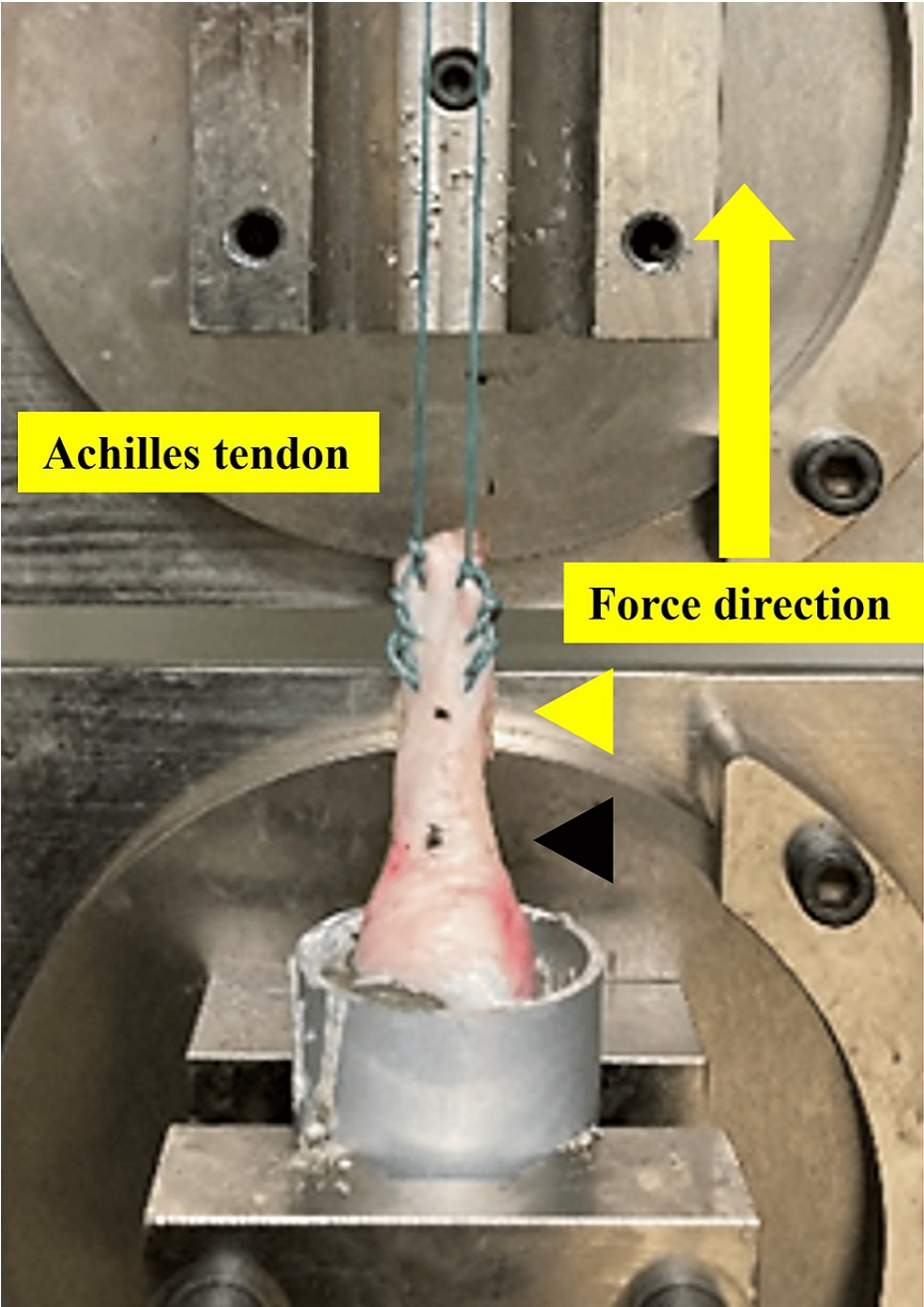
2023 Kurashina et al. Cureus 15(11): e49359. DOI 10.7759/cureus.49359

3 of 9

FIGURE 2: Biomechanical evaluation of Achilles tendon-calcaneus composite specimens

The specimen was mounted on a tensile tester using a set of specially designed grips. A cyclic loading test was performed by applying a tensile load to the Achilles tendon, parallel to its long axis. The black arrowhead indicates the insertion of the Achilles tendon into the calcaneus, and the yellow arrowhead indicates the insertion point 2.0 cm above the calcaneus. These areas were measured using Myoton PRO.
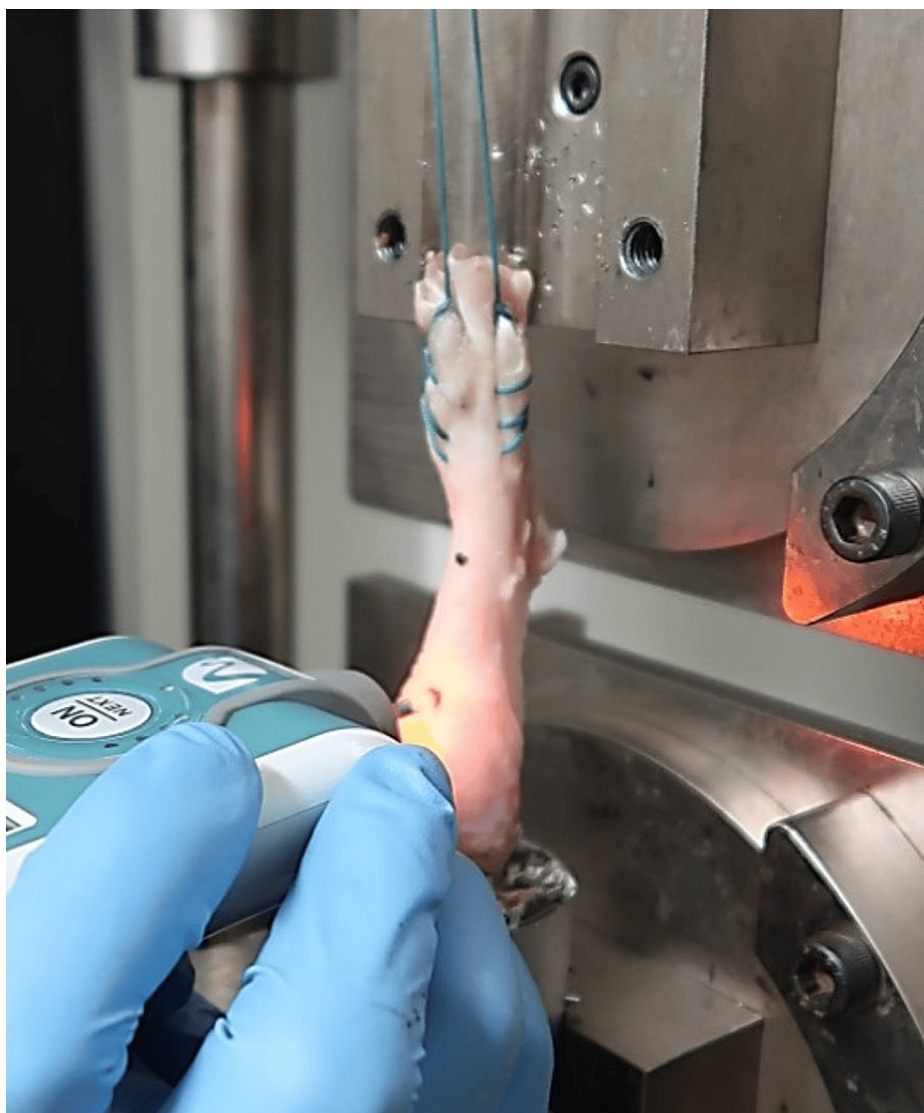
FIGURE 3: Procedure figure: Myoton PRO measurements at the insertion site of the Achilles tendon into the calcaneus

Statistical analysis

An a priori power analysis was performed using G* Power 3.1 (Franz Paul, Kiel, Germany). We investigated the primary outcome of the correlation between the dynamic stiffness, measured using Myoton PRO, and the length change, measured using the tensile testing machine, using Pearson's product-moment correlation coefficient. The sample size was calculated to require at least 26 samples, providing 80% power, with a Cohen effect size of 0.5 from a previous human AT study [15], to test the research hypotheses. As a secondary outcome, a paired t-test was performed to examine the differences in dynamic stiffness between AT0 and AT2. The intraclass correlation coefficient was used to evaluate the intraobserver reliability at AT0 and AT2. The reliability evaluation standard was judged to be high when the intraclass correlation coefficient was 0.75 or higher [23]. All data are presented as mean ± standard deviation. Statistical analyses were performed using Statistical Product and Service Solutions (SPSS) software, version 25.0 (IBM Corp., Armonk, NY, USA). Statistical significance was set at $P<0.05$.

Results

The dynamic stiffness measured using Myoton PRO was as follows: AT0, 717.6 ± 183.1 N/m; AT2, 467.4 ± 152.3 N/m. The dynamic stiffness at AT0 was significantly greater than that at AT2 ($P<0.001$) (Table *1*). The length change during cyclic loading was 1.8 ± 0.7 mm. The correlation between dynamic stiffness and length change during cyclic loading was moderately significant at AT0 (r=-0.61, 95% confidence interval (CI): -0.30 to -0.80)) and AT2 (r=-0.64, 95% CI: -0.36 to -0.83)) (all $P<0.001$) (Figures *4*, *5*). The intraobserver reliability was satisfactory (intraclass correlation coefficient: 1.3; AT0: 0.99 (95% CI: 0.98-1.00), AT2: 0.99 (95% CI: 0.98-1.00)).

Variables (n=28)	AT0	AT2	P values	95%CI
Dynamic stiffness (N/m)	717.6 ± 183.1	467.4 ± 152.3	< 0.001	202.3-298.2

TABLE 1: Dynamic stiffness(N/m) at AT0 and AT2 measured using Myoton PRO

AT0, Achilles tendon of the calcaneus insertion site; AT2, Achilles tendon of the 2.0 cm above the calcaneus; CI, confidence interval

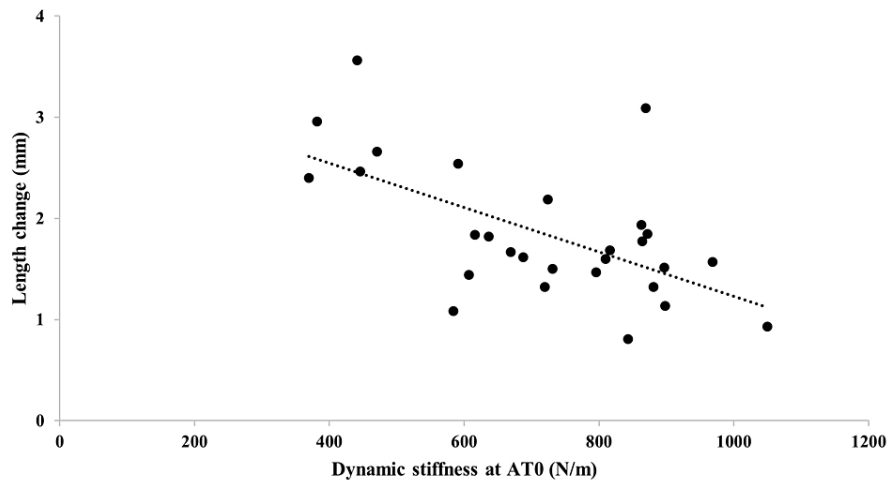Data are presented as mean ± standard deviation

FIGURE 4: Correlation between dynamic stiffness at the Achilles tendon of the calcaneus insertion site (AT0) and length change
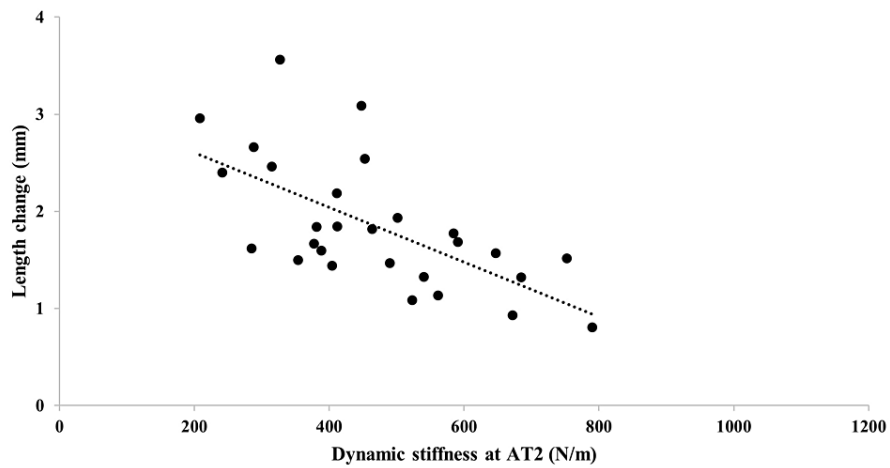

FIGURE 5: Correlation between dynamic stiffness at the Achilles tendon 2.0 cm above the calcaneus (AT2) and length change

Discussion

In this study, the dynamic stiffness measured using Myoton PRO was significantly negatively correlated with the length change measured using a biomechanical machine at AT0 and AT2. Furthermore, a significant difference in tissue stiffness was observed between AT0 and AT2 when Myoton PRO was used. These results suggest that stiffness evaluation of the AT using Myoton PRO can not only estimate the amount of translation in the longitudinal direction of the tissue but also distinguish the stiffness of each site.

2023 Kurashina et al. Cureus 15(11): e49359. DOI 10.7759/cureus.49359

6 of 9

Few reports have explored the correlation between Myoton PRO and other AT devices. Feng et al. reported a moderate correlation between Myoton PRO and shear wave elastography in human AT [15]. The present large-animal study showed that dynamic stiffness, measured using Myoton PRO, exhibited a moderate correlation with length change, measured using biomechanical machines, at both AT0 and AT2, consistent with the findings of the human AT study [15]. Biomechanical testing using tensile testing machines on porcine anterior cruciate and medial collateral ligaments has been reported [19-20]. Significant length changes, as observed with the long-axis method, indicate greater translation of the tissue and softer tissue. Consequently, the dynamic stiffness values measured using Myoton PRO consistently appeared lower. To our knowledge, this is the first study to validate the Myoton PRO device using other devices in large animals.

A significant difference in stiffness was observed between AT0 and AT2 using Myoton PRO. Chang et al. measured the AT0 and AT6 cm portions and found differences in dynamic stiffness [24]. Huang et al. reported that AT stiffness decreased in a distal-to-proximal pattern [25]. Therefore, stiffness may differ depending on the AT measurement unit. Chimenti et al. reported that the insertion at the AT increased the concentration of cartilage matrix proteins, such as type 2 collagen and aggrecan, along with a change in the morphology of tendon cells [26]. The stiffness of the AT decreased with increasing distance from the calcaneus. The difference in dynamic stiffness between AT0 and AT2 in this study indicates the ability of Myoton PRO to accurately capture tissue stiffness at each site.

Achilles tendinopathy necessitates adjusting the load while checking the condition of the AT during rehabilitation at hospitals and athletic rehabilitation in sports field settings [13]. Until now, detecting abnormalities solely through MRI and ultrasound imaging and accurately tracking progress has been challenging [6]. In the present study, the Myoton PRO and biomechanical machine demonstrated a moderate correlation. Recently, Myoton PRO was reported to reduce AT stiffness in patients with Achilles tendinopathy [5,27]. Myoton PRO can also noninvasively and easily assess the condition of the AT. In the future, if this handheld tool becomes more versatile and intervention loading is examined while closely monitoring the AT, exercise therapy that considers the appropriate loading of the AT according to individual conditions may be provided.

This study had several limitations. First, we did not examine interobserver reliability. However, previous studies have reported that interobserver reliability is high to very high, similar to intraobserver reliability [9,24]. Because Myoton PRO accepts measurements with a coefficient of variation of less than 3% to delineate data reliability, all measurements exceeding this recommended value were repeated [5]. Myoton PRO exhibits high reproducibility in both intra- and inter-observer reliability, and intraobserver reliability alone is considered sufficiently reliable. Second, only two points of the AT were measured. Achilles tendinopathy has been reported to occur along the AT between 2.0 and 6.0 cm from its insertion point [28]. Therefore, specimens, including the gastrocnemius and soleus muscles, may be created and measured as a complex. Finally, because the specimens had normal ATs, the relationship with the disease was unknown. In the future, freeze-thaw or collagenase techniques should be used to verify the validity of in vivo tendon degeneration in animal models using Myoton PRO [29,30].

Conclusions

Dynamic stiffness, measured using Myoton PRO, significantly correlated with length change, measured using a biomechanical machine, at AT0 and AT2. A significant difference in tissue stiffness was observed between AT0 and AT2 when Myoton PRO was used. Myoton PRO can be applied clinically to evaluate AT stiffness. Further research is required to monitor and manage tendon injuries in animal models and humans.

Additional Information

Author Contributions

All authors have reviewed the final version to be published and agreed to be accountable for all aspects of the work.

Concept and design: Wataru Kurashina, Tsuneari Takahashi, Hideyuki Sasanuma, Akihiro Saitsu, Katsushi Takeshita

Acquisition, analysis, or interpretation of data: Wataru Kurashina, Tsuneari Takahashi, Hideyuki Sasanuma, Akihiro Saitsu

Drafting of the manuscript: Wataru Kurashina, Tsuneari Takahashi, Hideyuki Sasanuma, Akihiro Saitsu, Katsushi Takeshita

Critical review of the manuscript for important intellectual content: Wataru Kurashina, Tsuneari Takahashi

Supervision: Wataru Kurashina, Tsuneari Takahashi, Katsushi Takeshita

Disclosures

Human subjects: All authors have confirmed that this study did not involve human participants or tissue. **Animal subjects:** Animal experiments were performed at our institution's biomechanical laboratory and conducted in accordance with the regulations of the Animal Care and Use Committee of the institution. Ethical approval by the committee was waived because of the ex vivo nature of this study. Issued protocol number Issued protocol number: Not applicable. **Conflicts of interest:** In compliance with the ICMJE uniform disclosure form, all authors declare the following: **Payment/services info:** All authors have declared that no financial support was received from any organization for the submitted work. **Financial relationships:** All authors have declared that they have no financial relationships at present or within the previous three years with any organizations that might have an interest in the submitted work. **Other relationships:** All authors have declared that there are no other relationships or activities that could appear to have influenced the submitted work.

Acknowledgements

References

1. von Rickenbach KJ, Borgstrom H, Tenforde A, Borg-Stein J, McInnis KC: Achilles tendinopathy: evaluation, rehabilitation, and prevention. Curr Sports Med Rep. 2021, 20:327-34. 10.1249/JSR.0000000000000855
2. de Jonge S, van den Berg C, de Vos RJ, et al.: Incidence of midportion Achilles tendinopathy in the general population. Br J Sports Med. 2011, 45:1026-8. 10.1136/bjsports-2011-090342
3. Kvist M: Achilles tendon injuries in athletes. Ann Chir Gynaecol. 1994, 18:173-201.
4. Longo UG, Ronga M, Maffulli N: Achilles tendinopathy. Sports Med Arthrosc Rev. 2009, 17:112-26. 10.1097/JSA.0b013e3181a3d625
5. Morgan GE, Martin R, Williams L, Pearce O, Morris K: Objective assessment of stiffness in Achilles tendinopathy: a novel approach using the MyotonPRO. BMJ Open Sport Exerc Med. 2018, 4:e000446. 10.1136/bmjsem-2018-000446
6. Dams OC, Reininga IH, Gielen JL, van den Akker-Scheek I, Zwerver J: Imaging modalities in the diagnosis and monitoring of Achilles tendon ruptures: a systematic review. Injury. 2017, 48:2383-99. 10.1016/j.injury.2017.09.013
7. Kayser R, Mahlfeld K, Heyde CE: Partial rupture of the proximal Achilles tendon: a differential diagnostic problem in ultrasound imaging. Br J Sports Med. 2005, 39:838-42. 10.1136/bjsm.2005.018416
8. Arya S, Kulig K: Tendinopathy alters mechanical and material properties of the Achilles tendon . J Appl Physiol (1985). 2010, 108:670-5. 10.1152/japplphysiol.00259.2009
9. Schneebeli A, Falla D, Clijsen R, Barbero M: Myotonometry for the evaluation of Achilles tendon mechanical properties: a reliability and construct validity study. BMJ Open Sport Exerc Med. 2020, 6:e000726. 10.1136/bmjsem-2019-000726
10. Alfredson H, Pietilä T, Jonsson P, Lorentzon R: Heavy-load eccentric calf muscle training for the treatment of chronic Achilles tendinosis. Am J Sports Med. 1998, 26:360-6. 10.1177/03635465980260030301
11. Silbernagel KG, Thomeé R, Thomeé P, Karlsson J: Eccentric overload training for patients with chronic Achilles tendon pain - a randomised controlled study with reliability testing of the evaluation methods. Scand J Med Sci Sports. 2001, 11:197-206. 10.1034/j.1600-0838.2001.110402.x
12. Millar NL, Silbernagel KG, Thorborg K, et al.: Tendinopathy. Nat Rev Dis Primers. 2021, 7:1. 10.1038/s41572-020-00234-1
13. Murphy MC, Debenham J, Bulsara C, et al.: Assessment and monitoring of Achilles tendinopathy in clinical practice: a qualitative descriptive exploration of the barriers clinicians face. BMJ Open Sport Exerc Med. 2022, 8:e001355. 10.1136/bmjsem-2022-001355
14. Mifsud T, Gatt A, Micallef-Stafrace K, Chockalingam N, Padhiar N: Elastography in the assessment of the Achilles tendon: a systematic review of measurement properties. J Foot Ankle Res. 2023, 16:23. 10.1186/s13047-023-00623-1
15. Feng YN, Li YP, Liu CL, Zhang ZJ: Assessing the elastic properties of skeletal muscle and tendon using shearwave ultrasound elastography and MyotonPRO. Sci Rep. 2018, 8:17064. 10.1038/s41598-018-34719-7
16. Kelly JP, Koppenhaver SL, Michener LA, Proulx L, Bisagni F, Cleland JA: Characterization of tissue stiffness of the infraspinatus, erector spinae, and gastrocnemius muscle using ultrasound shear wave elastography and superficial mechanical deformation. J Electromyogr Kinesiol. 2018, 38:73-80. 10.1016/j.jelekin.2017.11.001
17. Kurashina W, Iijima Y, Sasanuma H, Saito T, Takeshita K: Evaluation of muscle stiffness in adhesive capsulitis with Myoton PRO. JSES Int. 2023, 7:25-9. 10.1016/j.jseint.2022.08.017
18. Zuo Y, Luo J, Zhang X: A review on the use of porcine in tendon research . Ann Anat. 2023, 250:152166. 10.1016/j.aanat.2023.152166
19. Matsumoto Y, Takahashi T, Hatayama K, Kubo T, Higuchi H, Kimura M, Takeshita K: Medial meniscal ramp lesion repair concomitant with anterior cruciate ligament reconstruction did not contribute to better anterior knee stability and structural properties after cyclic loading: a porcine model. Arthrosc Sports Med Rehabil. 2021, 3:e1967-73. 10.1016/j.asmr.2021.09.019
20. Takahashi T, Takeshita K: In Vivo biomechanical evaluations of suture anchors for repairing grade 3 superficial medial collateral ligament injury in a porcine model. J Orthop Surg (Hong Kong). 2021, 29:10.1177/23094990211021536
21. Schneider S, Peipsi A, Stokes M, Knicker A, Abeln V: Feasibility of monitoring muscle health in microgravity environments using Myoton technology. Med Biol Eng Comput. 2015, 53:57-66. 10.1007/s11517-014-1211-5
22. Chen G, Wu J, Chen G, et al.: Reliability of a portable device for quantifying tone and stiffness of quadriceps

femoris and patellar tendon at different knee flexion angles. PLoS One. 2019, 14:e0220521. 10.1371/journal.pone.0220521

23. Enderlein G: Fleiss, J. L.: The design and analysis of clinical experiments. Wiley, New York - Chichester - Brislane - Toronto - Singapore 1986, 432 S., £38.35. Biom J. 1988, 30:304. 10.1002/bimj.4710300308

24. Chang TT, Feng YN, Zhu Y, Liu CL, Wang XQ, Zhang ZJ: Objective assessment of regional stiffness in Achilles tendon in different ankle joint positions using the MyotonPRO. Med Sci Monit. 2020, 26:e926407. 10.12659/MSM.926407

25. Huang J, Qin K, Tang C, Zhu Y, Klein CS, Zhang Z, Liu C: Assessment of passive stiffness of medial and lateral heads of gastrocnemius muscle, Achilles tendon, and plantar fascia at different ankle and knee positions using the MyotonPRO. Med Sci Monit. 2018, 24:7570-6. 10.12659/MSM.909550

26. Chimenti RL, Bucklin M, Kelly M, Ketz J, Flemister AS, Richards MS, Buckley MR: Insertional achilles tendinopathy associated with altered transverse compressive and axial tensile strain during ankle dorsiflexion. J Orthop Res. 2017, 35:910-5. 10.1002/jor.23338

27. Finnamore E, Waugh C, Solomons L, Ryan M, West C, Scott A: Transverse tendon stiffness is reduced in people with Achilles tendinopathy: a cross-sectional study. PLoS One. 2019, 14:e0211863. 10.1371/journal.pone.0211863

28. Maffulli N, Longo UG, Kadakia A, Spiezia F: Achilles tendinopathy. Foot Ankle Surg. 2020, 26:240-9. 10.1016/j.fas.2019.03.009

29. de Cesar Netto C, Godoy-Santos AL, Augusto Pontin P, et al.: Novel animal model for Achilles tendinopathy: controlled experimental study of serial injections of collagenase in rabbits. PLoS One. 2018, 13:e0192769. 10.1371/journal.pone.0192769

30. Tohyama H, Yasuda K, Uchida H: Is the increase in type III collagen of the patellar tendon graft after ligament reconstruction really caused by "ligamentization" of the graft?. Knee Surg Sports Traumatol Arthrosc. 2006, 14:1270-7. 10.1007/s00167-006-0092-z