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Quantitative Weight Bearing and non-weight Bearing Measures of Stiffness in the Achilles Tendon and Gastrocnemius Muscle

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SUMMARY

Objectives. To establish quantitative values of stiffness for the Achilles tendon (AT) and Gastrocnemius muscle (GM) in participants weight bearing and non-weight bearing.
Methods. Measurements of 25 participants taken bilaterally at 8 points along the AT, and 2 points at the GM included: Natural Oscillation frequency (F), dynamic stiffness (S), mechanical stress relaxation time (R), logarithmic decrement (D) and creep (C) were taken non-weight bearing (NWB) and weight bearing (WB) using the Myoton-PRO.
Results. Median WB F scores were significantly higher than NWB F scores. D was significantly ($P<0.005$) higher NWB than WB for both AT and GM. S decreased from point 1 to point 8. GM S measurements were significantly ($P<0.005$) higher WB to NWB. C increased along course of tendon in the NWB condition and was significantly ($P<0.005$) higher at the GM. R was significantly ($P<0.005$) higher in the NWB condition for the AT and GM. R incrementally increased along the course of the AT in both NWB and WB conditions.
Conclusions. There was an overall increased stiffness of the AT and GM during the weight bearing condition compared to the non-weightbearing condition. Further studies are required to develop a robust clinical application of this technology.

KEY WORDS
Achilles; gastrocnemius; soleus; stiffness; sports medicine

INTRODUCTION

It is commonly accepted in functional anatomy that the muscles of the human leg are under constant tension to maintain posture (1). This tension which influences the whole of the muscle and tendon unit is characterised by a biomechanical property known as stiffness. Stiffness determines the functional properties of tendon and the operational range of muscle fibres (2). Muscle and tendon stiffness is a commonly used mechanical parameter to study and can be thought of as the soft tissue response of deformation to a given force (3). During gait, elastic energy is stored in soft tissues throughout the stretch-shortening cycle and is released to create movement (1). The degree of stiffness in soft tissues is determined by the demands of the activity being undertaken such as standing, jumping, running etc (3). Greater stiffness values of soft tissues are associated with greater economy of motion and therefore changes in stiffness can become a marker for disease e.g. deconditioning (4). Reduced stiffness in tendons can result in elongation of the tendon which can in turn lead to tendon ruptures (5). In addition increased tendon viscoelasticity, a component of stiffness, can result in inefficiencies in elastic energy storage (6). The Achilles tendon and gastrocnemius muscle are frequently investigated due to their functional significance (7, 8, 9). The Achilles tendon has its insertion along the same line as the muscle and is known as a traction tendon (10). Its gastrocnemius muscle maintains near constant length during gait at minimal energy loss (2).
Methods for measuring the stiffness of soft tissues can be utilised for the clinical diagnosis of pathology, to assess

intervention or for the prediction of injury (3). The assessment of muscle and tendon stiffness in the clinical environment is often carried out by methods of palpation, very often with structures unloaded. This is a well established but subjective method of clinical evaluation, however does not produce objective data which can be utilised in the research environment (11) A novel and reliable method (12, 13, 14, 15) to measure stiffness of tendon and muscle tissue in-vivo utilised in this study was the MyotonPRO. The MyotonPRO is a handheld computerised device which generates a mechanical oscillation in soft tissues to measure non-invasively muscle or tendon stiffness at rest or during contraction. Soft tissue measurements taken with the MyotonPRO are captured simultaneously by its accelerometer and can be altered with underlying pathology (12,16). The quantitative mechanical measurements generated by the MyotonPRO provide the clinician with information about the pathological nature of the tissues under question (13).

The MyotonPRO has been used to measure the stiffness of muscle by analysing the muscle response to a local mechanical stimulation (12). The stiffness of muscle tissue is derived mainly from its viscoelastic properties (17) and can be defined as a ratio of change in force to change in length along the long axis of the tissue (18). Alamaki et al 2007 (19) defined muscle stiffness as the interaction between muscle viscoelastic properties, structures and neural regulation. The measurement of muscle or tendon stiffness by quantifying the resistance to a force applied perpendicularly has been demonstrated to be a valid method for comparing muscle at rest verses contracted (18). Bizzini et al 2003 (12) concluded that the MyotonPRO measures consistent and reliable viscoelastic stiffness of the gastrocnemius muscle. In addition to this there was a linear relationship with force output which suggested the MyotonPRO was measuring muscle stiffness rather than subcutaneous tissue. Therefore the MyotonPRO was utilised for this study due to its ability to measure the gastrocnemius muscle accurately.

Comparative technology used to measure soft tissue stiffness includes shear wave elastography. In comparison to shear wave elastography, which utilises Young's Modulus as a surrogate for stiffness, the MyotonPRO generates mechanical compression of anatomy and an oscillation of the tissue which is then used to calculate mechanical stiffness (N/m) (20). Resting stiffness of the gastrocnemius muscle measured with the MyotonPRO has been correlated with shear wave ultrasound elastography measurement of Young's Modulus (21).

The MyotonPRO has been shown to have increased intra-rater reliability in comparison to Shear Wave Elastography in measurement of the gastrocnemius muscle (20,21). In addition to this there are many limitations of strain elastography which may provide the MyotonPRO with an advantage with regards to its application. These include the diversity of ultrasound elastography techniques, poor inter and intra rater reliability and technical limitations e.g. distance between transducer and tissue measured (20, 22, 23).

To date, we found no study that investigated the Achilles tendon and Gastrocnemius muscle during weight bearing and non-weight bearing conditions using the MyotonPRO, particularly using multiple measurements along the Achilles tendon. The null hypothesis stated that there would be no significant differences in stiffness between the weight bearing and non-weight bearing conditions for the tendon and muscle measurements.

METHODS

Ethics statement

This study was conducted according to the Helsinki Statement, approved by the local and national ethics committee and as recommended by Padulo et al 201824. Potential participants were provided with written information about the study before providing written informed consent to participate. All participant data was anonymised.

Trial design

This is a case control study of 25 participants (median BMI= 25.8) (min:19.5 max:33) and median age = 39.6 (min:26 max:61) with asymptomatic Achilles tendons and Gastrocnemius muscles, recruited from staff at Cwm Taf University Health Board. The soft tissue mechanical data was measured by the chief investigator at left and right limbs using the MyotonPRO and was collected in weight bearing and non-weight bearing conditions. Participant data were age and gender matched.

The MyotonPRO is a Class 1 Medical Device according to European Medical Device Directive 93/42/CEE+2007/47/CE. There are five steps in the MyotonPRO measurement process i.e. application of pre-pressure (0.18N); a mechanical impulse with quick release (0.4N); recording of oscillation (200 ms); processing of raw signal (10ms) and computation of parameters (5ms). If one of these standard processes are not met during the measurement taken, the MyotonPRO will reject the measurement. The five mechanical parameters measured were: Natural Oscillation Frequency [Hz] (F); Logarithmic Decrement (D); Dynamic Stiffness [N/m] (S); Creep (C); (Deborah number) and Mechanical Stress Relaxation Time [ms] (R) (Myoton.com). No residual mechanical deformation or neurological response is produced from the impulse generated with the MyotonPRO of the tissue being evaluated. Therefore repeatability following initial measurement is of no concern for the weight bearing condition.

A comparison of pilot data was used to compare stiffness properties of weight bearing (WB) and Non-weight bearing (NWB) data. At the time of study design, there were no comparative analyses in the literature to utilise for the calculation. Based on a simple two sided t-test and assuming an average WB score at the Gastrocnemius of 29 and 52 for the Achilles Tendon for Natural Oscillation Frequency (F) Hz, an average NWB score of 18 at the Gastrocnemius and 31 at the Achilles Tendon for F and a common standard deviation of 8, and assuming a standard 5% significance threshold, a requirement of 4 participants (8 in total) to demonstrate a statistically significant difference with 90% power.

The inclusion criteria for both groups consisted of an age restriction of 18 to 70 years old to eliminate possible growth variations in younger participants and possible degeneration variation in older participants; with asymptomatic Achilles Tendons and Gastrocnemius Muscles. The exclusion criteria consisted of any history of previous surgical repair or rupture of the Achilles Tendon; Patients prescribed Quinalone antibiotics; A BMI of <35; History or symptoms of below knee soft tissue or joint pain; Known Rheumatological disease, diabetes and neurological or connective tissue disease. Participant activity levels were recorded as non-athlete recreational exercise

PROCEDURE

Measurements

were carried out non-weight bearing: participant lying prone on a couch with the Achilles tendon and Gastrocnemius muscle exposed and each foot resting at a neutral relaxed position, and weight bearing: participant standing with their feet and legs exposed (**figure 1**). The position of the foot as seen to the right in **figure 1** is in plantarflexion, allowing the Achilles tendon and Gastrocnemius muscle maximal relaxation. Participants were asked to relax on the couch before the measurements were taken non weight-bearing to ensure the muscle and tendon tissue was relaxed.

The MyotonPRO measured eight points along the Achilles tendon, each point at 2cm intervals (**figure 1 and figure 2**). The first point 6cm from the plantar aspect of the heel and the last point at the musculo-tendinous junction for all 25 participants (**figure 2**).

Two points (1 medial and 1 lateral) on the Gastrocnemius muscle were also measured at each central muscle belly

Figure 1. Participant measurement process. (Left: participant weight-bearing; Right: participant non-weight bearing / prone).

(**figure 2**), and as no significant differences were observed between these data sets the data were consolidated for analysis. Measurements were conducted on left and right limbs. A multi scan (five measurements) was taken with the MyotonPRO where the Median measurement was recorded at each point. As recommended by Myoton.com for validity, a measurement with a Coefficient of Variation less than 3% was accepted and any measurement above this recommendation was re-measured.

Data were imported from the MyotonPRO into Microsoft Excel and analysed using Minitab® 17 statistical software package and were found to be normally distributed using the Anderson-Darling method.

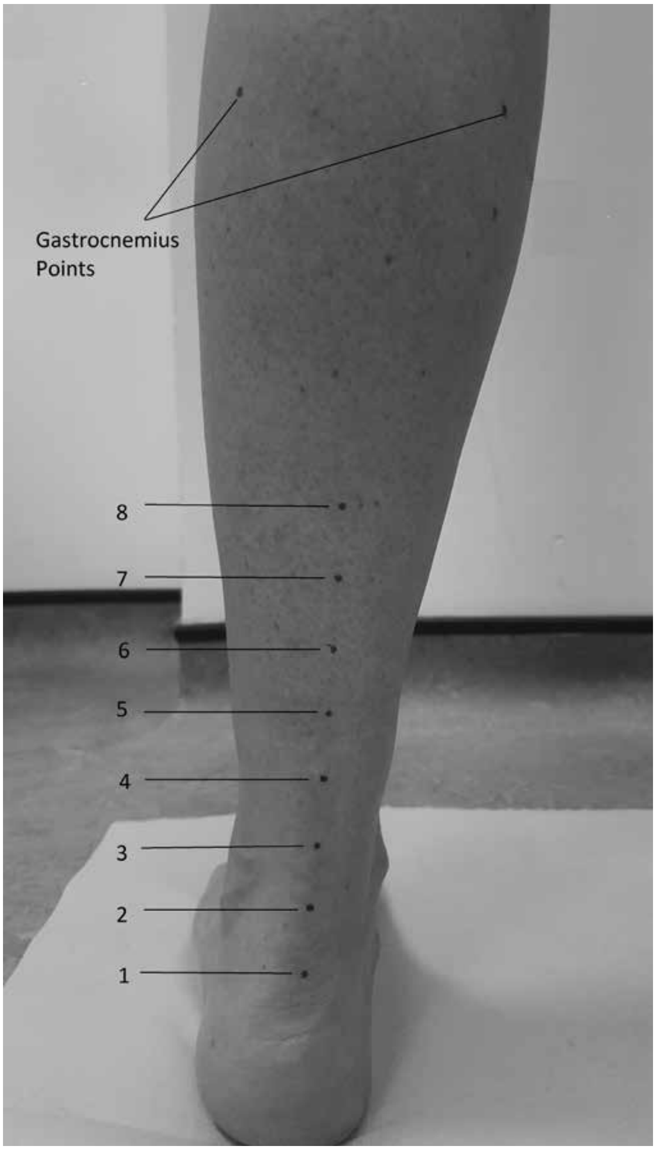

Figure 2. Participant measurement process with points 1-8 and Gastrocnemius points.

RESULTS

2-sided t-tests were carried out on the weight-bearing (WB) and non weight-bearing (NWB) data sets (**table I**) and an ANOVA procedure for each measurement point to determine the role of factors such as age, BMI and gender. The two-sample t-tests were made without any adjustments.

NATURAL OSCILLATION FREQUENCY (F)

There were significant ($P<0.005$) differences between weight bearing and non-weight bearing measurements at all eight points of the Achilles Tendon and the Gastrocnemius for the measurement F, signifying Tone (see **figure 3**).

The F measurements (WB and NWB) of **figure 3** demonstrate a graph with reduction in tonal properties of the tendon along its course (F measurement at Point 1 WB: 52.7Hz at Point 8: 22.6Hz. F measurement at Point 1 NWB: 31.8Hz at Point 8: 19.8Hz). This was observed with greater significance in the WB participants. The WB participants F scores were significantly ($P<0.005$) higher than the NWB participants.

LOGARITHMIC DECREMENT (D)

There were significant ($P<0.005$) differences between the WB and NWB measurements of D. With NWB D significantly lower at points 1,2,3,5 and 6. With the Gastrocnemius D showing higher NWB. The NWB data presented a graph with a Logarithmic Decrement gradually increasing over the length of the tendon (**figure 4**).

DYNAMIC STIFFNESS (S)

The WB Dynamic Stiffness (S) data (**figure 5**) presented with an incremental decrease from the insertion of the Achilles at point 1 to point 8 at its musclo-tendinous junction. The NWB data presented with a significant ($P<0.005$) decrease between point 1 and 2 followed by a less significant decrease along its course to point 7. A 2-sided t-test demonstrated significant ($P<0.005$) differences between NWB and WB data sets of the Achilles and Gastrocnemius muscle measurements. Suggesting the S of the Achilles tendon decreases incrementally from its insertion at the calcaneus to its musculotendinous junction, with this decrease being more significant with the tendon in the weight bearing condition.

Table I. Reference data of MyotonPRO measures.

	Point 1	Point 2	Point 3	Point 4	Point 5	Point 6	Point 7	Point 8	Gastroc
Median WB F	52.7	51.76	49.2	43.5	34.5	28.08	25.83	22.6	30.4
Median NWB F	31.8	31.78	27.84	25.04	23.35	21.2	20.66	19.8	18.96
Estimate of difference	20.9	19.98	21.34	18.44	11.05	6.83	5.18	2.79	11.45
P-value	P<0.005	P<0.005	P<0.005	P<0.005	P<0.005	P<0.005	P<0.005	P<0.005	P<0.005
Median WB D	1.32	1.307	1.283	1.194	1.157	1.09	1.51	1.575	1.09
Median NWB D	0.89	0.956	0.975	1.18	1.323	1.76	1.51	1.575	1.41
Estimate of difference	0.438	0.35	0.307	0.013	0.165	0.669	0	0	0.32
P-value	P<0.005	P<0.005	P<0.005	0.855	P<0.005	0.066	1	1	P<0.005
Median WB S	1464	1408	1327	1185	915	730	673	577	741
Median NWB S	1408	659	659	562	501	435	428.8	401.2	351.5
Estimate of difference	681.8	690.1	667.7	623.9	413.8	294.2	244.4	176	389
P-value	P<0.005	P<0.005	P<0.005	P<0.005	P<0.005	P<0.005	P<0.005	P<0.005	P<0.005
Median WB C	0.74	0.726	0.657	0.634	0.643	0.564	0.576	0.642	0.774
Median NWB C	0.44	0.479	0.513	0.619	0.71	0.79	0.875	0.908	1.032
Estimate of difference	0.292	0.246	0.144	0.015	0.066	0.225	0.299	0.266	0.258
P-value	P<0.005	P<0.005	P<0.005	P<0.005	0.067	P<0.005	P<0.005	P<0.005	P<0.005
Median WB R	6.47	6.49	6.35	6.63	7.6	7.86	8.46	9.9	10.82
Median NWB R	6.54	7.08	7.74	9.49	10.97	12.18	13.07	13.6	12.032
Estimate of difference	0.077	0.587	1.392	2.864	3.37	4.321	4.608	3.7	0.258
P-value	0.786	P<0.005	P<0.005	P<0.005	P<0.005	P<0.005	P<0.005	P<0.005	P<0.005

NWB, non weight-bearing; WB, weight-bearing

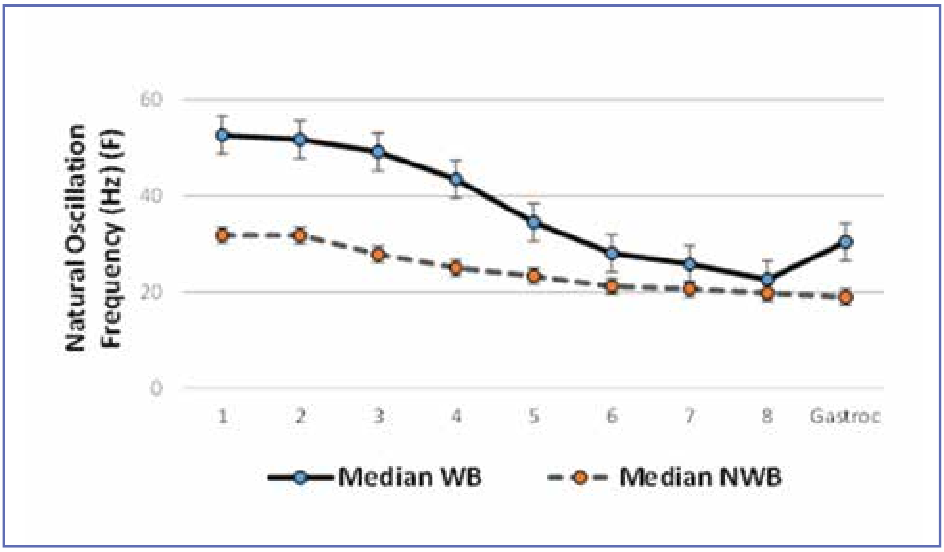

Figure 3. Weight bearing (WB) and Non-weight bearing (NWB) MyotonPRO measurements of Achilles Tendon (1-8) and Gastrocnemius (Gastroc) for Frequency (F) with standard error bars.

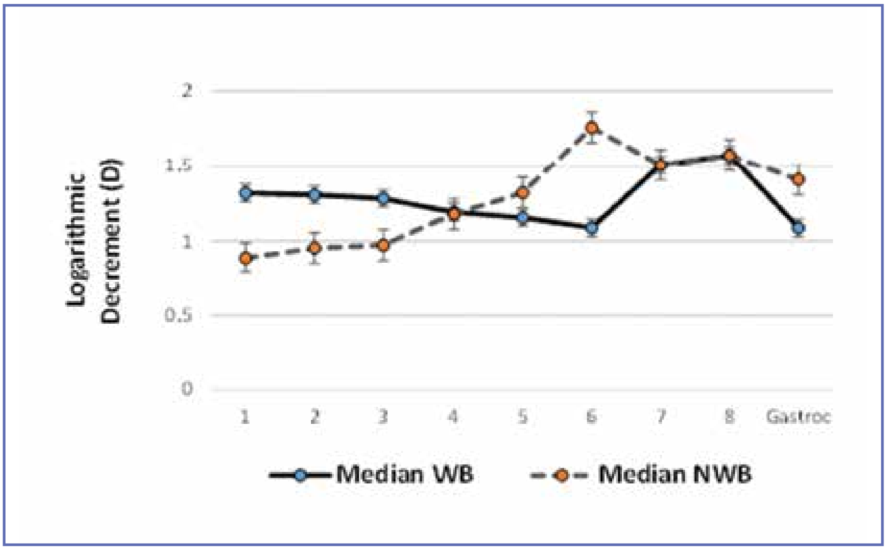

Figure 4. Weight bearing (WB) and Non-weight bearing (NWB) Myoton-PRO measurements of Achilles Tendon (1-8) and Gastrocnemius (Gastroc) for Logarithmic Decrement (D) with standard error bars.

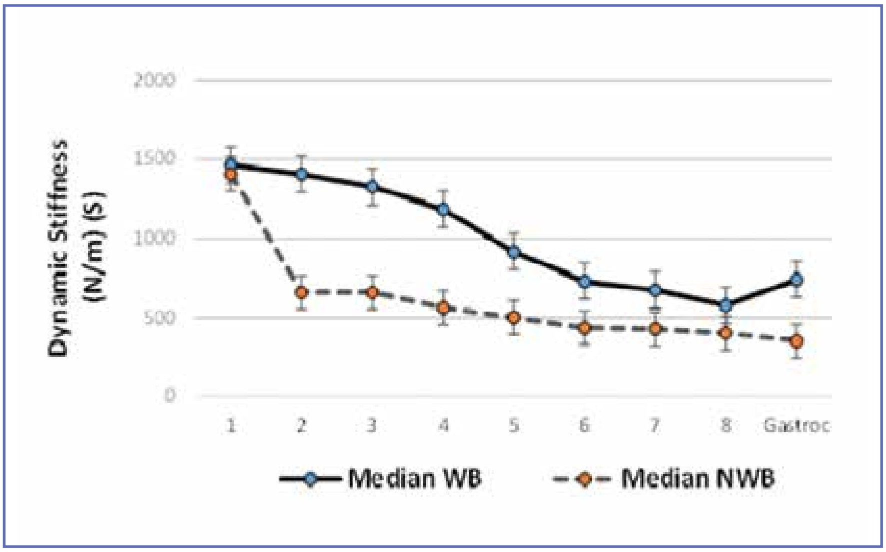

Figure 5. Weight bearing (WB) and Non-weight bearing (NWB) Myoton-PRO measurements of Achilles Tendon (1-8) and Gastrocnemius (Gastroc) for Dynamic Stiffness (S) with standard error bars.

CREEP (C)

The NWB Creep (C) data demonstrated an incremental increase from Point 1 to Point 8 (**figure 6**), where the WB data remained relatively constant. There were significant ($P<0.005$) differences between the NWB and WB data sets for both conditions. An incremental increase in elasticity was observed along the course of the Achilles tendon in the NWB condition.

MECHANICAL STRESS RELAXATION TIME (R)

Mechanical Stress Relaxation Time (R) data (**figure 7**) demonstrated significant ($P<0.005$) differences between the WB and NWB data sets from points 3 to 8 of the Achilles tendon and between the Gastrocnemius muscles WB and NWB. Both data sets demonstrated an incremental increase in R along each point, with higher R scores observed NWB.

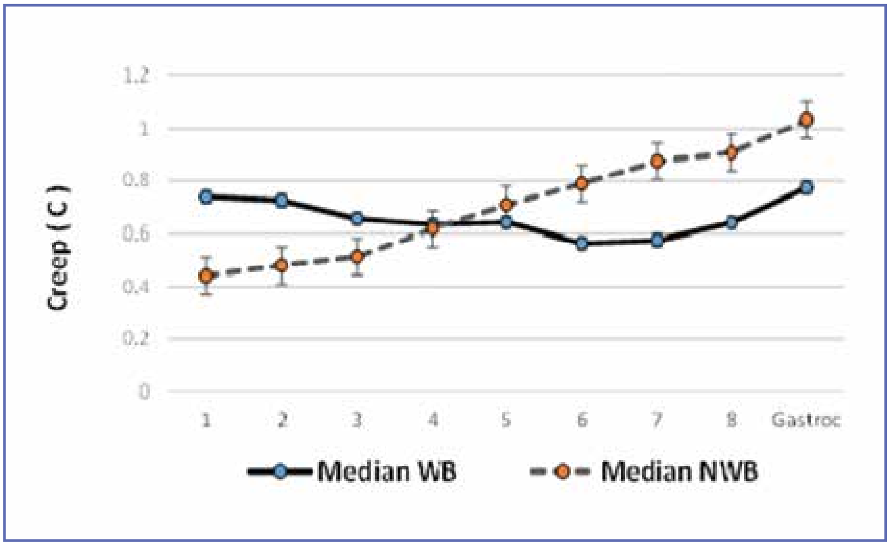

Figure 6. Weight bearing (WB) and Non-weight bearing (NWB) Myoton-PRO measurements of Achilles Tendon (1-8) and Gastrocnemius (Gastroc) for Creep (C) with standard error bars.

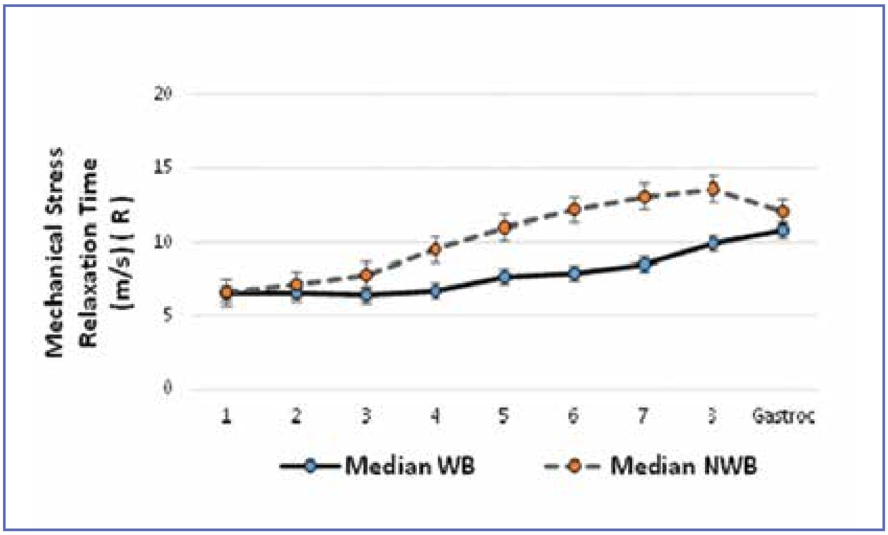

Figure 7. Weight bearing (WB) and Non-weight bearing (NWB) Myoton-PRO measurements of Achilles Tendon (1-8) and Gastrocnemius (Gastroc) for Mechanical Stress Relaxation Time (R) with standard error bars.

EFFECTS OF AGE, GENDER, BMI

There were 17 females to 8 males (**table II**). Both age, gender and BMI did not significantly affect scores.

DISCUSSION

This is the first study to evaluate the stiffness of the Achilles tendon along eight points and the gastrocnemius muscle at two points (medial and lateral) in an asymptomatic cohort of 25 participants. The null hypothesis stated that there would be no significant differences in the stiffness of the Achilles tendon and gastrocnemius muscle between the weight bear-

Table II. Participant demographics.

		Participants
BMI	Median	25.8 (min: 19.5 max: 33)
	SD	4.8
Age	Median	39.6 (min: 26 max: 61)
	SD	9.6
f:m	Number	18:07
	Ratio	39

f, female; m, male

ing and non-weight bearing conditions. The experimental data does not support this hypothesis. This study indicated significant differences in stiffness between the weight bearing (WB) and non-weight bearing (NWB) conditions for the participants. WB measures were significantly higher than NWB. Stiffness decreased incrementally along the course of the Achilles tendon in both WB and NWB conditions from its insertion at the calcaneus to its muscle-tendinous junction where the tissue is anatomically thinner. A previous study using computerised tonometery demonstrated an association between soft tissue tone and the thickness of the soft tissue structure (19). This may account for the decreasing stiffness observed along the course of the Achilles tendon in our study.

Vain et al. (2015) (25) carried out a comparative study using Myoton-3 to measure gastrocnemius stiffness between lying (passive resting muscle tone) and standing (postural muscle tone) in 27 healthy male participants. Measurements of the medial and lateral Gastrocnemius muscle with the Myoton-3 were pooled into one data set as per this current paper. This is a comparative study to our paper, however measurements were only carried out at the gastrocnemius muscle. In common with our study the tonal (F) properties of the gastrocnemius were found to be higher in the weight bearing group (25). However, there were no significant differences in elasticity between weight bearing and non-weight bearing conditions (25). Comparisons have also been previously made between stable and unstable conditions of the gastrocnemius muscle, using the MyotonPRO which suggested that ballistic muscle action may not influence stiffness (25).

The MyotonPRO has been previously demonstrated to be a reliable method for measuring the viscoelastic properties of the gastrocnemius muscle (12,23), in particular discriminating between three levels of muscle contraction (20). Our data demonstrated an increase in viscoelasticity along the course of the Achilles tendon, particularly in the NWB condition, whereas the main body of the Achilles tendon presented with reduced viscoelastic properties. These changes were observed less in the WB condition and Creep (a component of viscoelasticity) remained relatively constant along the course of the tendon. This may demonstrate an advantage for weight bearing and the storage of elastic energy within the tendon (1). The relatively consistent viscoelastic properties measured along the course of the Achilles tendon in the WB condition of our study suggest that it may be a beneficial characteristic to maintain low hysteresis of the tendon. Hysteresis is an important characteristic of tendons due to their ability to store large amounts of energy used for propulsion (6), where low hysteresis is associated with higher energy which can be used for movement. Increased tendon viscoelasticity can result in inefficiencies in elastic energy storage (6). However, previous research measured creep in the Achilles tendon longitudinally rather than transverse as with the MyotonPRO (26). Further research may therefore be required to compare longitudinal and transverse creep measurements of tissue before this modality is widely accepted.

There is little evidence of viscoelastic stiffness values for skeletal muscle in the literature (26). The majority of the research conducted on the viscoelastic stiffness of muscle has been in-vitro or more recently non-weight bearing (27). The viscoelastic properties of relaxed muscle have been thought to be as a result of the number of cross-bridges present in the tissue (28). Weak bond cross bridging results in a decreased stiffness of muscle tissue and contribute more towards passive muscle stiffness, rather than active force generation. Our study supports this concept and demonstrated a significant reduction in viscoelasticity of the gastrocnemius muscle in the WB condition.

In the NWB condition our data demonstrated significantly decreased elasticity of the Gastrocnemius muscle compared to the WB condition. This demonstrates a close biomechanical association between the Achilles tendon and gastrocnemius muscle. In addition to this may highlight an important functional characteristic of the ability to convert muscle contraction into skeletal movement. There was also a significant increase in elasticity of the Achilles tendon NWB compared to WB. This may be due to strain-hardening as observed in previous studies with shear wave elastography, where tendon stiffness increased significantly with lengthening or stretching of the tendon (28,29). This is thought to be as a result of the strain-stiffening behaviour of tendon tissue as the fibres increase in tension, preventing muscle from damage with increased loading. It has also been suggested that muscle elasticity increases with contraction and mechanical energy is released efficiently with minimum loss for plastic change or shape of muscle (2).

It has been previously thought that placing anatomical structures under tension, as carried out in our study from non-weight bearing to weight bearing, may allow measurement of the intramuscular connective tissue which is specific to muscle groups and their function (17). This may also be utilised to assess myofascial force transmission of the gastrocnemius and soleus complex (30). A study by Liu et al (2018) (31) measured varying degrees of tensile loading in healthy participants through modifying ankle joint dorsiflexion. In this study Achilles tendon stiffness increased with ankle joint dorsiflexion from a neutral foot position. In addition, Huang et al (32) assessed the passive stiffness of the gastrocnemius muscle, Achilles tendon and plantar fascia at different angles of ankle and knee flexion. In this study there was an increase in stiffness of the gastrocnemius muscle during knee extension. However regardless of ankle or knee position the Achilles tendon stiffness increased from distal to proximal. Our study supports these findings in both non-weight bearing and weight bearing positions. In addition to this our study utilised eight points of measurement at intervals of 2cm along the Achilles Tendon unlike Huang et al (32) who utilised three points of measurement at 0 cm (Achilles insertion at calcaneum), 3 cm and 6cm along the tendon. Our study procedure ensured that the foot position for the non-weight bearing condition was placed at a resting plantarflexed position to ensure tendon loading was reduced. The stiffness of the Achilles tendon from distal to proximal was higher weight-bearing and this therefore may be as a result of loading and not ankle dorsiflexion. This may also suggest that Achilles tendon stiffness is always higher distally, whether loaded or unloaded. However, the degree of stiffness seen in our study is significantly higher when loaded. It is likely that this demonstrates strain hardening under loading of the tissues with increase of logarithmic decrement during weight bearing (33).

Previous studies utilising the MyotonPRO have evaluated tendon and muscle stiffness unloaded (13,15) and utilising minimal points of measurement (32). In order to simulate loading during posture, gait or other activities, the clinician may benefit from carrying out measurement and assessment of soft tissues when loaded and unloaded. The clinical consideration may then be to establish any link between stiffness and injury (3). Where previously too much stiffness has been associated with bony injuries and too little stiffness with soft tissue injuries (34, 35). A comparative study utilising shear wave elastography (SWE) of four zones (musculo-tendinous junction, body, pre-insertional and enthesis) of the Achilles tendon complex with the foot dorsiflexed and planatarflexed have indicated comparative findings to our study (36). Petitpierre et al 2018 (36) found stiffness in the Achilles complex increased from its musculo-tendinous junction to its enthesis. Even though the study sample size was smaller than ours, the results support the findings of our study adding weight to the case for tendon assessment loaded and unloaded.

A final consideration when using the MyotonPRO in the measurement of human soft tissue is the effect of varying environments on soft tissue stiffness. One particular environment where soft tissue stiffness may vary is during micro or zero gravity. In order to test these conditions parabolic flights are utilised by the European Space Agency for microgravity research (37). The testing of MyotonPRO technology during microgravity conditions of parabolic flights has suggested there is a reduction in the state of tension of soft tissues (37). Other studies have investigated the effect of heat and cold on the elasticity of soft tissues. In particular Petrofsky et al (38) has suggested that heat and cold temperatures have a significant effect on the elasticity of knee ligaments. Therefore further research using the MyotonPRO on tendon and muscle tissues during varying temperatures may be beneficial.

LIMITATIONS

The limitations of this study are that electromyographical monitoring of the gastrocneius muscle were not carried out during non-weight bearing measurements. This may have added an additional control ensuring the resting condition of the muscle. Intra-day measurements were not carried out which may have provided data regarding repeatability and intra-day variance. The addition of blinding may have added additional validity. There may have been insufficient power in the data to conclude interactions of age, gender and BMI. The activity levels of participants were not utilised as a measure in this study and future research may benefit from investigating activity groups. A second evaluation method as control may have been useful for evaluation and comparison with the MyotonPRO data generated. The time of day and environmental characteristics may have an effect on the generation of data using the MyotonPRO, and it therefore may be beneficial for further research to reflect varying environmental characteristics.

CONCLUSIONS

This present study demonstrated significant differences between the weight bearing (WB) and non-weight bearing (NWB) conditions for both Achilles tendon and gastrocnemius muscle. These data suggest that stiffness is higher in the Achilles tendon and Gastrocnemius muscle during WB conditions with stiffness gradually decreasing along the course of the tendon from point 1 to point 8 from its insertion at the calcaneus to the muscle-tendinous junction. In the NWB condition there was an increase in viscoelasticity along the course of the tendon and overall increased viscoelasticity compared to WB. Achilles tendon and Gastrocnemius muscle elasticity was higher in the WB condition, with Achilles tendon elasticity decreasing along its course from its insertion at the calcaneus to its muscle-tendinous junction. Our findings support the argument for weight bearing and non-weightbearing assessment in future studies with the MyotonPRO and for the clinical environment to develop a robust clinical application of this technology.

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AUTHORS' CONTRIBUTIONS

Gafin Ericson Morgan, Role: Chief Investigator / Lead Author
Dr Rhodri Martin, Consultant Physician in Sports and Exercise Medicine, Role: Co-Author, Helen Welch, Physiotherapist, Role: Co-Author
Mrs Lisa Williams, Consultant Orthopaedic Surgeon, Role: Co-author
Pro.Keith Morris, Role: Statistician

CONFLICT OF INTERESTS

The authors declare that they have no conflict of interests.

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