Akdeniz Spor Bilimleri Dergisi

Mediterranean Journal of Sport Science

MJSS

ISSN 2667-5463

Investigation of Biomechanical and Viscoelastic Properties of Achilles Tendon in Professional Soccer Players According to Position

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DOI: https://doi.org/10.38021asbid.1474137

ORIGINAL ARTICLE

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Abstract

As in all performance athletes, too hard or too soft Achilles tendon (AT) affects athletic performance and increases the risk of injury in soccer players. The aim of this study was to know the tendon stiffness and mechanical properties of the tendon according to the positions and thus to apply appropriate training programs for the structural improvement of the mechanical properties of the AT according to the positions of the soccer players. In this study, 21 male professional soccer players with a mean age of 18.19±0.40 years, mean height of 180.48±6.25 cm, mean body weight of 70.71±7.82 kg, and mean BMI of 21.66±1.65 kg/m² were included. The mechanical and viscoelastic properties of the AT were evaluated with the highly reliable MyotonPro device (Myoton AS, Estonia). AT measurements of professional soccer players were performed 4 cm above the distal insertion of the tendon (calcaneal tubercle) after determining the distal insertion of the tendon in the prone position with the ankles hanging from the table in a neutral position. Although there was a significant result ($p<0.05$) when AT elasticity was analyzed by position, there was no significant result when post-doc pairwise comparison was analyzed. Statistical analysis showed that there was no significant difference between the positions played by soccer players in terms of AT mechanical properties. The fact that everyone in the team performed the same training and the measurements were performed on soccer players with similar body structure regionally affected the characteristics of the data obtained. In this sense, it is thought that examining the AT structures of soccer players according to their positions will contribute to improvements in strength output with training. In addition, the findings obtained from this study may support coaches and health professionals in determining the risk of tendon pathologies that may occur in athletes, in athlete rehabilitation, and in increasing and maintaining athletic performance. It is predicted that increasing the number of participants in future studies on the mechanical and viscoelastic properties of AT in soccer players will provide more reliable information to the researchers.

Keywords: *Soccer, Achilles Tendon, Tendon Stiffness, Myoton.*

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Profesyonel Futbolcularda Aşil Tendonunun Biyomekanik ve Viskoelastik Özelliklerinin Mevkilere Göre İncelenmesi

Öz

Tüm performans sporcularında olduğu gibi futbolcularda da aşil tendon'un (AT) çok sert ya da yumuşak olması atletik performansı etkilediği gibi sakatlık riskini de artırmaktadır. Bu çalışmanın amacı, tendon sertlik ve mekanik özelliklerinin mevkilere göre bilinmesi bu sayede futbolcuların mevkilerine göre AT mekanik özelliklerinin yapısal olarak geliştirilmesi için uygun antrenman programlarının uygulanmasıdır. Bu çalışmaya yaş ortalaması 18,19±0,40 yıl, boy ortalaması 180,48±6,25 cm, vücut ağırlığı ortalaması 70,71±7,82 kg, BKİ ortalamaları 21,66±1,65 kg/m² olan 21 erkek profesyonel futbolcu dahil edildi. AT mekanik ve viskoelastik özellikleri yüksek güvenirlikte MyotonPro cihazı (Myoton AS, Estonia) ile değerlendirildi. Profesyonel futbolcuların AT ölçümleri ayak bilekleri nötr pozisyonda masadan sarkacak şekilde yüz üstü yattıkları pozisyonda tendonun distal insersiyosu (kalkaneal tüberkül) belirlendikten sonra bu noktanın 4 cm yukarısından gerçekleştirildi. AT elastisitesi mevkilere incelendiğinde anlamlı bir sonuç ($p<0.05$) çıkmasına rağmen Post-Doc ikili karşılaştırmaya bakıldığında anlamlı bir sonuç çıkmamıştır. İstatistiksel analiz, futbol branşı ile ilgilenen sporcuların oynadıkları mevkiler arasında AT mekanik özellikleri açısından anlamlı bir fark olmadığını göstermiştir. Takımda herkesin aynı antrenmanı yapması ve bölgesel olarak benzer vücut yapısında futbolculara ölçümlerin uygulanması elde edilen verilerin özelliklerini etkilemiştir. Bu anlamda futbolcuların mevkilerine göre AT yapılarının incelenmesinin, antrenmanlarla kuvvet çıktısında gelişmelere katkı sağlayacağı düşünülmektedir. Ayrıca bu çalışmadan elde edilen bulguların antrenörler ile sağlık çalışanlarına, sporcularda oluşabilecek tendon patolojileri riskini belirlemede, sporcu rehabilitasyonunda, atletik performansı artırmada ve sürdürmede destek olabilir. Futbolcularda AT'un mekanik ve viskoelastik özellikleri ile ilgili ileride yapılacak çalışmalarda katılımcı sayılarının arttırılmasının araştırmacılara daha güvenilir bilgiler vereceği öngörülmektedir.

Anahtar kelimeler: *Futbol, Aşil Tendon, Tendon Sertliği, Myoton.*

Received: 26.04.2024

Accepted: 09.06.2024

Online Publishing: 28.06.2024

Introduction

A tendon is a fibrous connective tissue with tensile strength when subjected to high resistances, which functions to transfer load from muscle to bone. The longest and most durable tendon in our body is the Achilles Tendon (AT). The AT, which is a continuation of the calf muscles and terminates at the heel, has the task of storing and releasing the existing mechanical load during eccentric-concentric phases such as running, jumping and throwing. The mechanical properties of this tendon are influenced by biochemical responses, as well as the continuous repetition of eccentric and concentric phases of the lower extremity muscles in order to do the given work depending on the effort of the athletes during training will cause the muscles to need more energy. This will lead to muscle stiffness and tendon stiffness (Malliaras et al., 2013; Gavronski et al., 2007; Gapeyeva and Vain, 2008). In addition, it has been observed that age, gender and body mass index have a slight effect on the mechanical properties of the tendon, but this effect is only effective in the AT organ (Morgan et al., 2018).

Mechanical and viscoelastic properties of the AT such as stiffness, tone, elasticity may change according to the intensity of the exercise and this change was found to be most pronounced in sprinters, followed by endurance athletes. It is very important to have information about the mechanical properties of the AT in individuals performing sports activities at different intensities, to obtain information about the effect of exercise intensity on AT adaptation processes, to understand the importance of these changes on the human musculoskeletal system and to achieve optimal athlete performance (Usgu et al., 2020; Arampatzis et al., 2007). There are some measurement methods in the literature to determine the viscoelastic and mechanical properties of AT. With the Myoton device, one of them, the muscle tone of the lower extremity; (F) natural oscillation frequency (Hz), biomechanical properties; (S) dynamic stiffness (N/m), (D) elasticity, viscoelastic properties; (R) relaxation time (ms), (C) relaxation rate and deformation time components can be measured (Orner et al., 2018).

The fact that there is a change in the tone, mechanical properties and viscoelastic properties of the tendon as a result of injuries that occur or may occur in the tendon structure of the athlete after training is sufficient for us to understand how important the concept of tendon stiffness is in athletes (Bohm and Mersmann, 2015). It is known that the stiffness of tendon mechanical properties increases as athletes train for years, which is a requirement of the sports branch they are interested in, and that they have stiffer AT structures over time (Heinemeier and Kjaer, 2011). The stiffness and all mechanical properties of the tendon also affect the possibility of injury. The AT shows lower stiffness in case of damage due to overtraining or impact. With disruptions in central nervous system transmission, agonist, antagonist and synergist muscles may bring some negativities in a way that they cannot perform their duties. In this sense, it can be said that the effect of AT mechanical properties on the athlete's force production is extremely important (Chang and Kulig, 2015). The mechanical properties of the AT may also affect other athletic performance characteristics in soccer players since the AT stiffness is exposed to 4 times more pressure than many other tendons due to lower extremity muscle stiffness with training (Kongsgaard et al., 2005; Usgu et al., 2020).

Changes seen in the organism of athletes due to appropriate and adequate training, structural development will bring along the cross-sectional increase and thickening of tendon structures. As a matter of fact, it has been observed that the strength training applied by athletes leads to an increase in tendon structure. It is thought that appropriate strength and endurance training can prevent tendon pathologies that athletes may encounter (Frankewycz et al., 2018; Couppe et al., 2009). In terms of athlete performance, too much or too little stiffness in the muscle mass of athletes can be a risk factor for injury (Butler et al., 2003). It is important for football players to know these structural differences in terms of their own performances in order to improve the situation and conditions or to avoid injury.

The aim of this study was to know the tendon stiffness and mechanical properties of lower extremity tendons according to their positions, and thus to apply appropriate training programmes for the structural development of AT mechanical properties of soccer players according to their positions. The study was designed according to this hypothesis based on the assumption that there will be differences in muscle tendon structures of soccer playing in different positions and performing the same training programmes depending on the performance components required by their positions (jump, change of direction, reaction and endurance) and that these differences will have positive and negative effects on the optimal performance of the athlete. According to the results obtained, it is thought that knowing the differences in muscle tendon structures of soccer players in terms of position will be important in terms of both improving athlete performance and determining injury risks.

Materials and Methods

Research Model

The hypothesis of our research is that there will be a difference in AT structures in soccer players depending on their positional characteristics. Survey research model was applied fort his study.

Population Sample Group

Necessary permissions were obtained from Gaziantep Hasan Kalyoncu University School of Physical Therapy and Rehabilitation for the use of the MyotonPro Device, which is the test device before the tests to be performed. After consulting with Gaziantep Soccer Club, which has a professional status in the province where the device is located, the tests were carried out in the facilities of this club and the population of the study consisted of soccer players playing in this club and the sample consisted of elite soccer players who met the inclusion criteria.

According to the G*Power analysis result, the programme gave the number of participants to participate in the study as 22. Twenty-one elite soccer players aged between 18 and 40 years with no history of lower extremity orthopedic injury in the last 12 months were included in the study. Informed consent form was signed by the individuals who agreed to participate in the study. The athletes were instructed to inform the investigator in case of any side effects during the evaluations and application. AT assessments the evaluations took an average of 6 minutes for each soccer player.

Data Collection Tools

A descriptive evaluation form including demographic information of the athletes was used as a data collection tool. Demographic and anthropometric measurements (gender, age, height, weight, body mass index) were recorded. Position and dominant lower extremity were questioned during training and games. Assessments were performed on the dominant side. To ensure the accuracy of the measurements, participants were instructed to refrain from strenuous activity five hours before the test and not to take any medication that would interfere with the test.

The stiffness and mechanical properties of the AT were evaluated with the highly reliable MyotonPro device (Myoton AS, Estonia). AT measurements of the participants were taken with the athletes lying face down with their ankles hanging from the table in a neutral position. The AT measurement was performed 4 cm above this point after determining the distal insertion of the tendon (calcaneal tubercle) (Liu et al., 2018). The myotonometric measurement was repeated three times and averages were recorded. Only measurements with a coefficient of variation of less than 3% were considered. Otherwise, the measurements were repeated. The foot with which the athlete kicked the ball was questioned to determine the dominant side.

Data Evaluation

Statistical analyses were performed using SPSS v23 software. Kolmogorov-Smirnov test was used to determine the normality of the data. Mean and standard deviation values were taken to describe the data. The power and efficiency of nonparametric test is less than parametric test. The Kruskal Waris test, which is a nonparametric test, was applied for the comparison of the groups due to the small number of participants and the absence of strict assumptions. The confidence interval was chosen as 95% and values below $p < 0.05$ were considered statistically significant.

Ethics of Research

During the current research, "Higher Education Institutions Scientific Research and Publication Ethics Directive" has been acted within the framework.

Results

Twenty-one professional soccer players, all male, participated in the study. The mean age of the athletes was 18.19±0.40 years, mean height was 180.48±6.25 cm, mean body weight was 70.71±7.82 kg, and mean BMI was 21.66±1.65 kg/m². Descriptive data of the soccer players are shown in Table 1.

Table 1

Descriptive Information

Professional Soccerers (n=21)	**Mean±Std**
Age (years)	18,19±0,40
Height (cm)	180,48±6,25
Weight (kg)	70,71±7,82
BMI $(kg/m)^2$	21,66±1,65

(Mean: Average, Std: Standard Deviation, BMI: Body Mass Index, n: Number of Individuals)

Table 2

Achilles Tendon (AT) Tone, Biomechanical and Viscoelastic Properties of Soccer Players

Tone, Biomechanical and Viscoelastic Properties (AT)	X^2	**p**
F	5.67	0.225
S	4.83	0.305
D	11.52	0.021*
R	5.06	0.281
C	4.36	0.359

F:Tone [Hz], S: Dynamic Stiffness [N/m], D: Elasticity, R: Relaxation Time [m/s], C: Relaxation and Deformation Time. ($p<0.05$)

A significant result (D: 0.021; $p<0.05$) was found when AT elasticity (D) was analyzed according to the positions of the soccer players.

Table 3

Comparison of Achilles Tendon (AT) Elasticity (D) According to Soccer Players Positions

Soccer Players' Positions		**W**	**p**
Defender	Forward	2.191	0.530
Defender	Goalkeeper	-1.897	0.665
Defender	Midfielder	-1.449	0.844
Defender	Center-back	2.319	0.472
Forward	Goalkeeper	-2.449	0.415
Forward	Midfielder	-2.585	0.358
Forward	Center-back	-0.816	0.979
Goalkeeper	Midfielder	3.464	0.103
Goalkeeper	Center-back	2.777	0.284
Midfielder	Center-back	2.887	0.246

($p<0.05$)

Although there was a significant result ($p<0.05$) when AT elasticity (D) was analyzed according to the positions, there was no significant result when Post Doc pairwise comparison was analyzed. Statistical analysis showed that there was no significant difference between the playing positions of the athletes interested in soccer in terms of AT mechanical properties.

Discussion

In soccer players, as in all performance athletes, too hard or too soft AT affects athletic performance and increases the risk of injury. The aim of this study was to know the tendon stiffness and mechanical properties of the tendon according to the positions and to apply appropriate training programmes for the structural development of the mechanical properties of the AT according to the positions of the soccer players. This study was conducted on the hypothesis that AT mechanical and viscoelastic properties of professional soccer players would be different by using myotonometric measurements because they have different positional characteristics required by the branch in different positions. In the study which included 21 professional male soccer players, mean age was 18.19±0.40 years, mean height was 180.48±6.25 cm, mean body weight was 70.71±7.82 kg, and mean BMI was 21.66±1.65 kg/m^2. AT contributes to the production of optimal force and utilization of available energy by contraction and relaxation in the lower extremity muscles. It also enables the gastrocnemius-AT complex to work more effectively in activities such as walking, running and jumping depending on biomechanics, muscle tone and stiffness components (Alexander and Bennet-Clark, 1977; Obst et al., 2016). This indicates the existence of a strong relationship between the gastrocnemius and AT (Epro et al., 2018). In line with the studies conducted in the past, it is thought that athletes have a stiffer tendon structure as a result of the training they do during their athletic life, and the reason for this may be the training they are exposed to and adapt to. (Arampatzis et al., 2010). In another study, it was observed that these athletes reached higher muscle-tendon stiffness values after a plyometric training programme applied to athletes for 14 weeks (Foure et al., 2012).

In our study, AT muscle tone; (F) natural oscillation frequency (Hz), biomechanical properties; (S) dynamic stiffness (N/m), (D) elasticity, viscoelastic properties; (R) relaxation time (ms), (C) relaxation rate and deformation time components were examined. Although tendon elasticity (D), which is a biomechanical property, showed a significant result ($p<0.05$) when analyzed according to the positions of the soccer players, there was no significant result when Post Doc pairwise comparison was analyzed. Statistical analysis showed that there was no significant difference between the playing positions of soccer players in terms of AT mechanical and viscoelastic properties. In a previous study in the literature, muscle-tendon stiffness in soccer players was investigated. According to the results obtained, it was determined that there was no difference in terms of muscle-tendon stiffness according to the positions played by soccer players (Faria et al., 2013). In another study examining the muscle-tendon stiffness of soccer players playing in different positions, it was found that goalkeepers had a stiffer muscle-tendon structure than soccer players playing in other positions due to the explosive nature of their movements during training or during the match (Arampatzis et al., 2007). In other studies, Heinemeier and Kjaer the reason why there was no significant difference in the muscle-tendon mechanical properties of soccer players playing in different positions, even though the characteristics required by their positions were different, was explained by the fact that the soccer players were exposed to the same loads in the same training. In another study, Cristi-Sanchez et al. showed that the AT stiffness of soccer players playing in different positions in the same team was similar, and the reason for this was that they practiced the same training (Heinemeier and Kjaer, 2011; Cristi-Sanchez et al., 2019). Konrad and Tilp concluded that there were no differences between positions similar to our study (Konrad and Tilp, 2018).

It is very important for coaches to know the tendon mechanical and viscoelastic properties of soccer players playing in different positions in order to take the necessary precautions for the following process. As a matter of fact, strength training applied to soccer players may cause an increase in the tendon structure of the soccer player. In a study, it was found that there was a significant relationship between power, strength and speed parameters obtained during jumps in athletes and AT stiffness, which affected athletic performance (Bojsen-Moller et al., 2005). In the literature, it has been emphasised that there is an increase in lower extremity tendon stiffness with plyometric training and a significant improvement in jump performance of athletes with this increase. On the other hand, other studies have argued that plyometric training applied to athletes during the season does not increase tendon stiffness and that weight training to be applied to athletes instead of these exercises can increase lower extremity tendon stiffness. (Wu and Lien, 2010; Kubo and Morimoto, 2007). In the study conducted by Kubo et al. it was shown that long distance runners with the best grades had lower AT stiffness values than long distance runners with the worst grades (Kubo, 2015). Usgu et al. stated that the AT stiffness of professional soccer players was higher than that of runners, while the flexibility performance of athletes, which is one of the determinants of athletic performance, was less. It can be said that static stretching may have positive effects on lower extremity muscle and tendon elasticity in soccer players, but these athletes may experience some problems related to the lower extremity because they do not take this into consideration (Usgu et al., 2020; Polat et al., 2019). On the other hand, in another study, it was determined that the AT values of middle and long distance runners with the best grades were more rigid than other middle and long distance runners (Rogers, 2015). In another study conducted with athletes in different branches, it was emphasized that AT mechanical properties did not show a significant difference between athletes (Kurihara et al. 2012). There is no clear information in the literature that there is a correlation between

AT and optimal performance. Therefore, we cannot talk about a clear relationship between AT stiffness and performance. In our study, the fact that tendon stiffness and mechanical properties did not show a significant difference in terms of position can be attributed to the fact that the athletes performed the same training and these trainings were designed according to the requirements of the branch. We can attribute this situation to the fact that soccer coaches in our country follow the current training methods and include extra training programmes in order to eliminate positional differences against the same training of soccer players.

Conclusion

In this sense, it is thought that examining AT structures in soccer players will contribute to changes in strength output. In addition, the findings obtained from this study may support coaches and health professionals in determining the risk of tendon pathologies that may occur in athletes, in athlete rehabilitation, and in increasing and maintaining athletic performance. We think that increasing the number of participants in future studies on the mechanical and viscoelastic properties of AT in soccer players will provide more reliable information to researchers.

Limitation

In order to carry out similar studies in soccer and different branches with different hypotheses with large participants, the device used should be easily accessible. As the limitations of our research, we can say that it is limited to the Myoton Pro device.

Ethics Committee Permission Information

Ethics review board: T.C. Manisa Celal Bayar University Faculty of Medicine Health Sciences Ethics Committee Decision Form

Date of ethics assessment document: 22.02.2023

Issue number of the ethics evaluation document: 2392

References

Alexander, R. M., & Bennet-Clark, H. C. (1977). Storage of elastic strain energy in muscle and other tissues. *Nature, 265*(5590), 114-7.

Arampatzis, A., Karamanidis, K., De Monte, G., Morey-Klapsing, G., & Stafilidis, S. (2007). Mechanical properties of the triceps surae tendon and aponeurosis in relation to ıntensity of sport activity. *Journal of Biomechanics*, *40*(9), 1946-1952.

Arampatzis, A., Peper, A., Bierbaum, S., & Albracht, K. (2010). Plasticity of human achilles tendon mechanical and morphological properties in response to cyclic strain. *J*. Biomech, *43*, 3073-3079. doi: 10.1016/j.jbiomech.2010.08.014

Bohm, S., Mersmann, F., & Arampatzis, A. (2015). Human tendon adaptation in response to mechanical loading: A systematic review and meta-analysis of exercise ıntervention studies on healthy adults. *Sports Med Open, 1:7*.

Bojsen-Møller, J., Magnusson, S. P., Rasmussen, L. R., Kjaer, M., & Aagaard, P. (2005). Muscle performance during maximal ısometric and dynamic contractions is ınfluenced by the stiffness of the tendinous structures. *J. Appl Physiol. Sep; 99*(3), 986-94. doi: 10.1152/japplphysiol.01305.2004.

Butler, R. J., Crowell III, H. P., & Davis, I. M. (2003). Lower Extremity Stiffness: Implications for performance and ınjury. *Clinical Biomechanics, 18*(6), 511-517.

Chang, Y. J. & Kulig, K. (2015). The neuromechanical adaptations to achilles tendinosis. *J Physiol. 593, 3373-3387.*

Couppe, C., Hansen, P., Kongsgaard, M., Kovanen, V., Suetta, C., Aagaard, P., Kjaer, M., & Magnusson, S. P. (2009). Mechanical properties and collagen cross-linking of the patellar tendon in old and young men. *J. Appl. Physiol, 107*, 880-886.

Cristi-Sánchez I., Danes-Daetz C., Neira A., Ferrada W., Yáñez Diaz R., & Silvestre Aguirre R. (2019). Patellar and achilles tendon stiffness in elite soccer players assessed using myotonometric measurements. *Sports Health. 11*(2), 157-62.

Epro, G., McCrum, C., Mierau, A., Leyendecker, M., Brüggemann, G. P., & Karamanidis, K. (2018). effects of triceps surae muscle strength and tendon stiffness on the reactive dynamic stability and adaptability of older female adults during perturbed walking. *J. Appl. Physiol, 124*, 1541-1549. doi: 10.1152/ japplphysiol.00545.2017

Faria, A., Gabriel, R., Abrantes, J., Wood, P., & Moreira, H. (2013). Mechanical properties of the triceps surae: Differences between football and non-football players. *Journal of Sports Sciences, 31*(14), 1559-1567.

Fouré, A., Nordez, A., & Cornu, C. (2012). Effects of plyometric training on passive stiffness of gastrocnemii muscles and achilles tendon. *European Journal of Applied Physiology, 112*(8), 2849-2857.

Frankewycz, B., Penz, A., Weber, J., da Silva N. P., Freimoser, F., Bell, R., Nerlich, M., Jung, E.M., Docheva, D., & Pfeifer, C. G. (2018). Achilles tendon elastic properties remain decreased in long term after rupture. *Knee Surg. Sport. Traumatol. Arthrosc, 26*, 2080-2087.

Gapeyeva, H., & Vain, A. (2008). Principles of applying myoton in physical medicine and rehabilitation. *Methodical Guide Tartu*. 22.

Gavronski, G., Veraksits, A., Vasar, E., & Maaroos, J. (2007). Evaluation of viscoelastic parameters of the skeletal muscles in junior triathletes. *Physiol Meas. 28*, 625-37.

Heinemeier, K., & Kjaer, M. (2011). In vivo ınvestigation of tendon responses to mechanical loading. *J Musculoskelet Neuronal Interact,11*, 115-123.

Kongsgaard, M., Aagaard, P., Kjaer, M., & Magnusson, S. P. (2005). Structural achilles tendon properties in athletes subjected to different exercise modes and in achilles tendon rupture patients. *J Appl Physiol*, 1965-1971.

Konrad, A., & Tilp, M. (2018). Muscle and tendon tissue properties of competitive soccer goalkeepers and midfielders. *Ger J. Exerc Sport Res*., *48*, 245-251 https://doi.org/10.1007/s12662-018-0510-7

Kubo K., Miyazaki D., Shimoju S., & Tsunoda N. (2015). Relationship between elastic properties of tendon structures and performance in long distance runners. *Eur J. Appl Physiol*, *115*, 1725-1733.

Kubo, K., Morimoto, M., Komuro, T., Yata, H., Tsunoda, N., Kanehisa, H., & Fukunaga, T. (2007). Effects of plyometric and weight training on muscle-tendon complex and jump performance. *Med. Sci. Sports Exerc., 39*, 1801-1810.

Kurihara, T., Sasaki, R., & Isaka, T. (2012). Mechanical properties of achilles tendon in relation to various sport activities of collegiate athletes. 30th Annual Conference of Biomechanics in Sports. 183. Melbourne

Liu, C. L., Li Y. P., Wang, X. Q., & Zhang, Z. J. (2018). Quantifying the stiffness of achilles tendon: Intra- and ınter-operator reliability and the effect of ankle joint motion. *Med Sci Monit. Jul., 14*(24), 4876-4881. doi: 10.12659/MSM.909531.

Malliaras, P., Kamal B., Nowell A., Farley T., Dhamu H., Simpson, V., Morrissey, D, Langberg, H., Maffulli, N., & Reeves, N. D. (2013). Patellar Tendon Adaptation in Relation to Load-Intensity and Contraction Type. *J. Biomech*, *46*(11), 1893-1899

Morgan, G. E., Martin, R., Williams, L., Pearce, O., & Morris, K. (2018). Objective assessment of stiffness in achilles tendinopathy: A novel approach using the MyotonPRO. *BMJ Open Sport & Exercise Medicine, 4*(1), e000446. doi:10.1136/ bmjsem-2018-000446

Obst, S. J., Newsham-West, R, & Barrett, R. S. (2016). Changes in achilles tendon mechanical properties following eccentric heel drop exercise are specific to the free tendon. Scand. *J. Med. Sci. Sports, 26,* 421-431. doi: 10.1111/sms.12466.

Orner, S., Kratzer, W., Schmidberger, J., & Grüner B. (2018). Quantitative tissue parameters of achilles tendon and plantar fascia in healthy subjects using a handheld myotonometer. *J Bodyw Mov Ther.*, *22*, 105-11.

Polat, S., Edis Ç., & Catıkkas, F. (2019). Effects of dynamic and static stretching exercises applied in warm-up session on performance. *Turkish Journal of Sport Sciences*, *2*(1), 31-38.

Rogers, S. A. (2015). Relationships between multiple mechanical stiffness assessments and performance in middle-distance runners [Master's Thesis]. Auckland, New Zealand: Auckland University of Technology.

Usgu, S., Yakut, Y., & Cınar, M. A. (2020). Comparison of viscoelastic properties of achilles tendon in elite runners and soccer players. *Turkish Journal of Sports Medicine, 55*(4), 276-283.

Wu, Y. K., Lien, Y. H., Lin, K. H., Shih, T. T., Wang, T. G., & Wang, H. K. (2010). Relationships between three potentiation effects of plyometric training and performance. *Scand. J. Med. Sci. Sports*. *20*, 80-86. doi: 10.1111/j.1600-0838.2009.00908.x.