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ORIGINAL

CHARACTERISTICS OF THE PATELLAR AND ACHILLES TENDONS IN SENIOR BADMINTON PLAYERS

CARACTERÍSTICAS DEL TENDÓN ROTULIANO Y DE AQUILES EN JUGADORES SENIOR DE BÁDMINTON

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ABSTRACT

The purposes of the study were to describe the structural and mechanical properties of the patellar and Achilles tendons in senior badminton players (>35 years) and to detect possible asymmetries between dominant and non-dominant lower limb. Two hundred and six senior badminton players (52.2±9.6 years old) who participated in the 2018 Senior European Championship volunteered to participate in the study. The structural properties (thickness, width and cross-sectional area) by a Logiq® S8 ultrasound system and the mechanical properties (elasticity, tone, stiffness and elastography index) with myotonometry and sonoelastography of the patellar and Achilles tendons were assessed. Non-dominant Achilles tendon showed greater values for the thickness (5.34±19.90%, p=0.027) and width (1.57±8.52%, p=0.036) than those of the dominant tendon, while the dominant patellar tendon showed higher values for tone (2.09±12.96%, p=0.002) and stiffness (4.41±21.11%, p=0.002) compared to the non-dominant one.

KEYWORDS: Asymmetry, tendon structure, Myotonometry, elastography, badminton.

RESUMEN

Los objetivos del estudio fueron describir las propiedades estructurales y mecánicas de los tendones rotuliano y de Aquiles en jugadores senior (>35 años) de bádminton y detectar posibles asimetrías entre el lado dominante y no dominante. La muestra estuvo compuesta por 206 jugadores senior de bádminton (Edad: 52.2±9.6 años) que participaron en el campeonato de Europa Senior en 2018. Se evaluaron las propiedades estructurales (grosor, anchura y área de sección transversal) por medio de un ecógrafo Logiq® S8 y las propiedades mecánicas (elasticidad, tono, rigidez e índice de elastografía) con miotonometría y sonoelastografía de los tendones rotuliano y de Aquiles. Los resultados mostraron que fueron mayores el grosor (5.34±19.90%, p = 0.027) y la anchura (1.57±8.52%, p=0.036) en el tendón de Aquiles no dominante mientras que el tendón rotuliano dominante mostró unos valores mayores para el tono (2.09±12.96%, p=0.002) y para la rigidez (4.41±21.11%, p=0.002) respecto al no dominante.

PALABRAS CLAVE: Asimetría, estructura del tendón, miotonometría, elastografía, bádminton.

1. INTRODUCTION

Badminton is considered to be one of the most complete and well liked indoor sports in the world, and has acquired the status of a spectator sport in several oriental countries (China, Japan, India, Indonesia,…) and some Northern European ones (Denmark, England,…) resulting in it being practised by approximately 200 million people (Chin et al., 1995) and achieving high levels of popularity in these countries. In spite of being one of the most commonly practised sports, it is considered a “very safe sport” (Cogan & Brown, 1999) and of low injury risk compared to other sports (Jorgensen & Winge, 1987). However, badminton players also suffer injuries due to the volume of hours accumulated on the court during training and competitions. Jorgensen and Winge (1987) in their study of elite badminton players based on a prospective self-recording of injuries, showed that the mean of global incidence of injuries in a recreational club and for elite-level badminton was 0.85 injuries per year or 2.9 injuries per 1,000 hours of practice. Idrottsskador (1994) in a study on injuries in licensed players from 1986-1990, published by a Swedish sports insurance company, revealed that badminton had a frequency of 2-5 injuries annually per 1,000 hours of practice. The annual injury incidence was low compared with other individual sports like for example squash (4-10 injuries/1,000 hours of practice) or alpine skiing (12-29 injuries/1,000 hours of practice).

Badminton requires dynamic movements from the lower body and, like the other one-sided sports, the load of movements and impacts mainly falls on the dominant limb, This characteristic causes greater eccentric efforts in the dominant lower limb during braking that are produced at the end of each approach to the net and side zones as well as in the jumps (Abian-Vicen et al., 2012). The physical demands of badminton suggest that injuries are more frequent in the lower limbs, as they represent 58% of the total (Jorgensen & Winge, 1987). Furthermore, the incidence is higher in the dominant leg due to the one-sided nature of the sport (Miyake et al., 2016). The most severe overuse injuries in badminton are related to tendons (Fahlstrom et al., 2002; Jorgensen & Winge, 1987).

The habitual weight bearing activities cause changes in the structural and mechanical properties of athletes’ tendons and muscles (Murach et al., 2015; Mosteiro-Muñoz, et al., 2017) and are related to overuse injuries (Boesen et al., 2011; Couppe et al., 2008). Regarding the mechanical properties of the tendon, stiffness is one of the most important in the muscle-tendon unit and also in the structure of the free tendon, especially in all sports involving very explosive movements like badminton (Ramos Álvarez et al., 2016; Valldecabres et al., 2019). Badminton rallies last a mean of ~10 s during which the player performs high-intensity efforts, and rest intervals of ~25 s, causing work density of about 0.4 (Abián-Vicén et al., 2018; Abián et al., 2014). The elastic properties of the tendons are especially important in movements involving the stretch-shortening cycle (jumps, lunges…) to optimise the storage and subsequent release of elastic energy in explosive movements (Murphy et al., 2003). Thus, the elastic properties of the tissues are useful for establishing a descriptive model of the mechanical properties of the tendons in badminton players.

The majority of investigations study the incidence of injuries in badminton (Couppe et al., 2008; Jorgensen & Winge, 1987; Miyake et al., 2016) but we have only found one that analysed the chronic adaptations of the myotendinous structures to the continued practice of this sport, in a limited sample (Bravo-Sánchez et al., 2019). It is necessary to understand the effects of prolonged badminton practice on the muscular and tendinous structures of the lower limbs to be able to analyse possible asymmetries and subsequently work to prevent myotendinous injuries. Knowledge of the main sports injuries is very important for badminton players and injury prevention is one of the topics that most concern coaches and physical trainers, especially those that train the best badminton players. It should be borne in mind that the mean time to recover from a badminton injury is relatively long (~48 days) (Jorgensen & Winge, 1987).

In spite of the importance of overuse injuries in badminton, we have not found many studies that explain the mechanical and structural differences between the dominant and non-dominant lower limbs in badminton players. Thus, the aims of this study were to describe the structural and mechanical properties of the tendons in the lower limbs of senior badminton players (> 35 years) and detect possible asymmetries in the patellar and Achilles tendons in the dominant and non-dominant lower limb, caused by the continued practice of badminton.

2. MATERIAL AND METHODS

2.1. Participants and general procedure.

Two hundred and six senior badminton players (> 35 years, 110 men and 96 women) who participated in the European Senior Badminton Championship, in 2018, volunteered to participate in this investigation. The participants had a mean age of 52.2 ± 9.6 years, height of 173.0 ± 10.1 cm, body mass of 74.7 ± 13.3 kg, fat percentage of 15.3 ± 7.6 %, 33.7 ± 12.7 years of badminton practice and peak weekly hours of training of 9.8 ± 5.7 hours-week^{-1}. The players' laterality was recorded to differentiate between the dominant and non-dominant lower limb. The dominant upper limb was the side that corresponded with the preferred hand for playing badminton. The dominant lower limb was the side that corresponded to the preferred hand for playing badminton.

All the participants were informed orally and in writing of the purpose and procedures of the investigation and signed their informed consent before the start of the study. The participants were free to leave the activity at any time without the need to provide an explanation and without their leaving implying any sanction. Players were excluded from the sample if they had an injury or any pain that would prevent them from performing their customary sports practice and also those who had had an injury or surgery in the previous two years or surgery on the Achilles tendon at any time. The study was approved by the Ethics Committee of Clinical Research at the Toledo Hospital complex (Spain) (number 72, dated 11/05/2017) according to the principles of the latest version of the Declaration of Helsinki.

Fat percentage was measured using bioelectric impedance with a Tanita TBF 300 (Tanita Corp., Tokyo, Japan). The structural examinations of the patellar and Achilles tendons were performed with a Logiq® S8 ultrasound (GE Healthcare, Milwaukee, WI, USA) with a multi-frequency linear probe (8-12 MHz (ML6-15-D; General Electric Healthcare system), in 2D mode and an image depth of 4cm. ImageJ version 1.43 software was used to analyse the images. The mechanical properties of both tendons were recorded with a Myoton® Pro handheld myotonometer (Myoton AS, Tallinn, Estonia) and with the same probe to measure the sonoelastographic (SE) data connected to the same ultrasound used for the structural characteristics (Logiq® S8). The ultrasound images were taken of both lower limbs at previously marked anatomical points and following the criteria determined by Boesen et al. (2011). The reference points for the measurements were: 1cm caudal with regard to the inferior border of the patella for the patellar tendon and 3 cm cranial with regard to the insertion in the calcaneus for the Achilles tendon.

The structural variables of the tendon that were analysed were:

- Thickness: the distance between the superficial and deep zone of the epitenon measured in cm.
- Width: the distance between the lateral points of the epitenon measured in the cross section in cm.
- The cross-sectional area (CSA): The surface area of the tendon measured in the cross section in cm^2.

The mechanical variables recorded in the tendons using myotonometry were as follows: (Gavronski et al., 2007):

- Elasticity (D): defined as the ability of a tissue to recover its original shape when an internal or external force measured in arbitrary units (A.U.) is applied. It is characterised by the capacity of the tissue to dissipate mechanical energy during each oscillation period. The greater the value the more elastic the tissue (Gavronski et al., 2007).
- Tone or Oscillation Frequency (FR) characterises the state of the tissue after a mechanical tap and is measured in Hz. The higher the value the tenser the tissue or the higher its tone (Gavronski et al., 2007).
- Stiffness: represents the resistance of a tissue to the force that changes its shape recorded in $N \cdot m^{-1}$. The greater the value the more energy needed to modify the shape of the tissue. We can define it as the biomechanical property of the muscle or tendon explaining the resistance to the deformation caused by an external force that produces an initial change of its shape. The greater the value, the stiffer the tissue.

2.2.- Measurement of the structural properties using ultrasound

A grey-scale high-resolution ultrasound examination was performed in B mode on the patellar and Achilles tendons on both the dominant and non-dominant sides. For the patellar tendon, the players were examined lying on their backs with the knee flexed to 20º and the muscles relaxed (Rasmussen, 2000). For the Achilles tendon, the players were examined lying on their fronts with their foot hanging over the edge of the bed in a neutral position (Klauser et al., 2013). The marks made previously to the measurement were also made in this position so as not to influence the results. These measurements have been used in previous research and have shown acceptable reliability (Rasmussen, 2000). Measurements were taken of the thickness of the patellar and Achilles tendons (Figure 1) and the thickness of the subcutaneous fat with the ultrasound probe placed in the sagittal plane and perpendicular to the skin. The CSA and width of the patellar and Achilles tendons were measured at the same points on the axial plane (Figure 2).

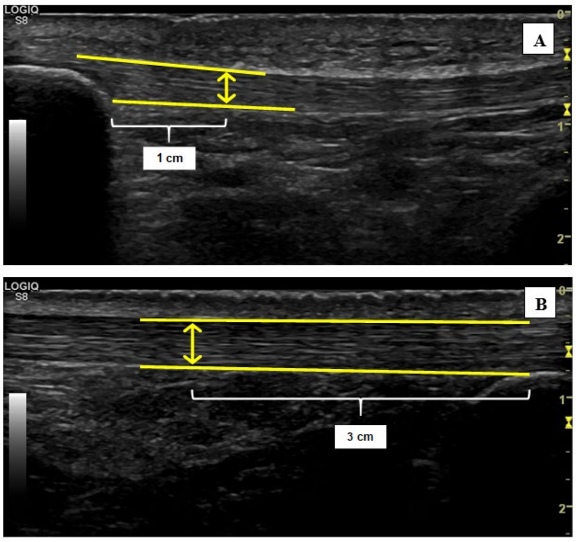

Figure 1: Measurements of the thickness of the patellar (A) and Achilles (B) tendons.

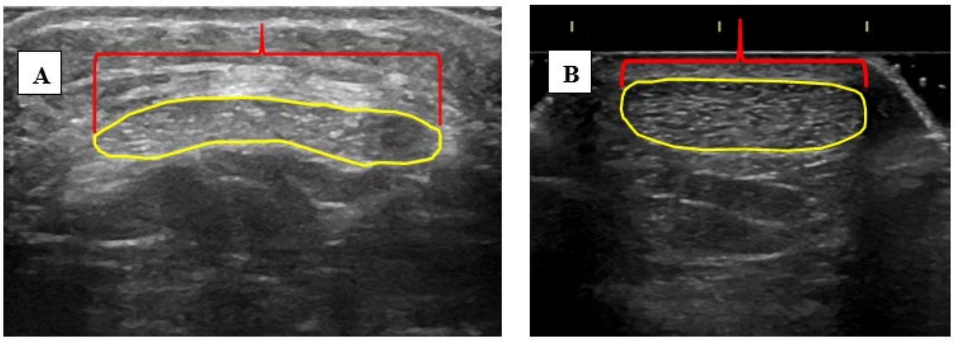

Figure 2: Measurements of the CSA and width of the patellar (A) and Achilles (B) tendons.

2.3. Measurement of the mechanical properties using sonoelastography.

Sonoelastography makes it possible to calculate the stiffness of a tissue by applying a known pressure and assessing the adaptation of the tissue to the pressure exerted (Park & Kwon, 2011). It is performed by applying a light repetitive tap with a handheld probe. The elastogram appears in a rectangular region of interest with a colour code in real time superimposed on the image in the B mode (Klauser et al., 2013). The tension of the tissue or the elastographic index (EI) was measured using a circular region of interest (ROI) of 4-5mm in diameter (ROI) (Drakonaki et al., 2009) within the rectangular frame of interest. The B mode ultrasound is used to locate the zone for measurement. Once the tendon has been located, a colour map is superimposed on the grey scale indicating the response of the underlying tissues to the rhythmic taps performed by the operator. The colour ranges from blue (a very stiff tissue like bone) to red (elastic tissues) and is translated into a numerical score from 1 to 5 (1 indicates very stiff tissue or absence of elasticity and 5 elastic tissues) which generates an elstographic index. The quality of the taps is confirmed using the green scale located on the left of the screen. The best image derived from at least three cycles of compression-relaxation was used to assess the tension ratio (Klauser et al., 2013). The tension ratio of the tendon was calculated automatically by the sonoelastography software comparing the ROI with the adjacent tissues (Turan et al., 2013). The sonoelastographic measurement was taken in the longitudinal axis at the same points described above in each of the tendons (patellar and Achilles) analysed. We selected for analysis the images that included a complete thickness of the structures with the subcutaneous layer and the bone surface (Figure 3) and a range of pressure quality of 5-7 out of 7.

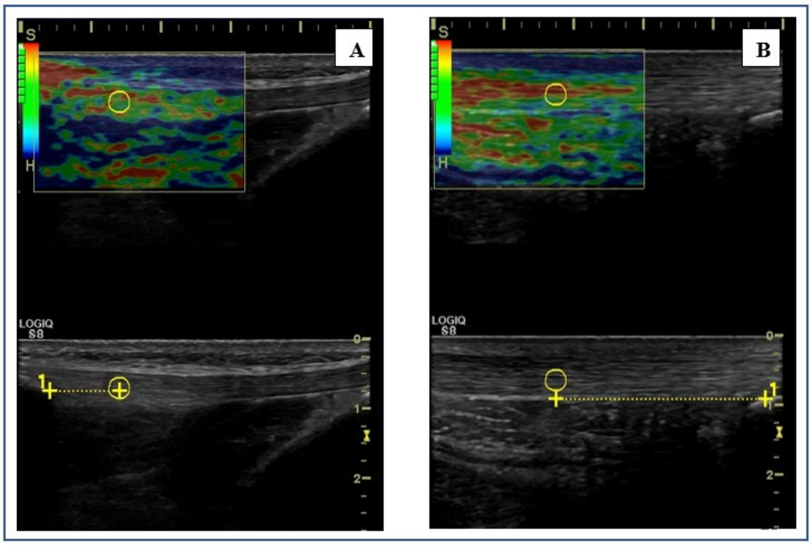

Figure 3. Measurements of the ratio of deformation of the patellar (A) and Achilles (B) tendons.

2.4. Measurement of the mechanical properties using the Myoton PRO

The mechanical properties of the tendons in the lower limbs were measured with a Myoton® Pro digital palpation device (Myoton AS, Tallinn, Estonia). The measurements with the Myoton® Pro were taken on the structures of the dominant and non-dominant lower limbs (patellar and Achilles tendons) placing the probe (3mm diameter) perpendicular to the skin on the tendon in question at the previously described points. The device produces a mechanical tap of 0.18 N and 15 ms on the surface of the skin which induces natural oscillations which are dampened by the underlying tissues (Aird et al., 2012). These oscillations were recorded by an accelerometer connected to the measurement device which has no friction within it. Two series of predefined measurements of 10 mechanical taps were separated by one second and with a one-minute rest between series. The device itself provides the mean of these measurements. The Myoton® Pro has shown high levels of reproducibility and validity for assessing myotendinous mechanical properties (Pruyn et al., 2016).

2.5.- Statistical analysis

A Microsoft Excel spreadsheet (Microsoft, Spain) was used to store the results. The statistical analysis was performed with the statistical programme SPSS v. 22.0 (SPSS Inc., USA**)**. All the data are presented as means ± standard deviations. The normality of all the variables was confirmed with the Kolmogorov-Smirnov test and they all proved to have a normal distribution. The structural and mechanical properties were compared between the dominant and non-dominant lower limbs using Student’s t-test for related samples. The percentage of difference between both lower limbs, calculated using the formula [100% - (non-dominant / dominant · 100%)] (Aird et al., 2012; Niemelainen et al., 2011) was used to analyse asymmetries. For the myotonometric variables, a difference of up to 5% in the same structure between the two sides, was still considered symmetric (Aird et al., 2012). A significance level of $p<0.05$ was used in all the tests performed.

3. RESULTS

3.1 Structural properties of the tendon.

The senior badminton players did not reveal differences between the dominant and non-dominant side in the structure of the patellar tendon; however, asymmetries were observed in the structure of the Achilles tendon. The thickness of the non-dominant Achilles tendon was 5.34 ± 19.90 % greater than that of the dominant tendon ($p = 0.027$). Moreover, the values for the width of the non-dominant Achilles tendon were 1.57 ± 8.52 % greater than those of the dominant tendon. No differences were found in the CSA or in the subcutaneous fat between the dominant and non-dominant Achilles tendons. The values of the structural properties of both tendons are shown in Table 1.

Table 1. Results of the structural characteristics measured in senior badminton players (mean ± standard deviation).

	Dominant	Non-dominant	Δ (CI 95%)	p value
Patellar tendon				
Thickness (cm)	0.36 ± 0.10	0.36 ± 0.11	0.00 ± 0.11 (-0.02 to 0.01)	0.413
Width (cm)	3.17 ± 0.37	3.20 ± 0.37	-0.03 ± 0.36 (-0.07 to 0.02)	0.151
CSA (cm^2)	0.96 ± 0.22	0.97 ± 0.23	-0.01 ± 0.17 (-0.03 to 0.02)	0.325
Subcutaneous fat (cm)	0.49 ± 0.12	0.49 ± 0.13	-0.00 ± 0.09 (-0.01 to 0.01)	0.473
Achilles tendon				
Thickness (cm)	0.56 ± 0.13	0.58 ± 0.11	-0.02 ± 0.11 (-0.03 to -0.01)	0.027*
Width (cm)	1.66 ± 0.19	1.67 ± 0.18	-0.02 ± 0.14 (-0.04 to -0.01)	0.036*
CSA (cm^2)	0.80 ± 0.25	0.80 ± 0.21	0.00 ± 0.19 (-0.03 to 0.03)	0. 472
Subcutaneous fat (cm)	0.16 ± 0.05	0.16 ± 0.05	0.00 ± 0.04 (-0.01 to 0.01)	0. 453

CSA: cross sectional area; *significance level $p < 0.05$.

3.2 Mechanical properties of the tendon

The SE examinations found no differences in the EI either in the patellar or the Achilles tendons. The values of SE for both tendons are shown in Table 2.

Regarding the myotonometric variables, the dominant patellar tendon showed tone values which were 2.09 ±12.96 % greater than the non-dominant tendon ($p = 0.002$), with 39.1% of the players recording differences greater than 5%. The stiffness of the dominant patellar tendon was 4.41 ± 21.11 % higher than the non-dominant patellar tendon ($p = 0.002$), with 48.8 % of the players recording differences greater than 5%. No differences were found in elasticity between the dominant and non-dominant patellar tendons. The values of the mechanical properties of the patellar tendons are shown in Table 2.

The elasticity of the dominant Achilles tendon was 1.25 ± 32.41 % greater than the non-dominant Achilles tendon (p = 0.009), with 47.1% of the players recording differences of over 5%. No differences were found in tone or stiffness between the dominant and non-dominant sides in the Achilles tendon. The values for the mechanical properties of the Achilles tendon are shown in Table 2.

Table 2. Results of the mechanical properties measured in senior badminton players (mean ± standard deviation).

	Dominant	Non-dominant	Δ (CI 95%)	p value
Patellar tendon				
FR (Hz)	22.63 ± 3.14	21.92 ± 2.89	0.71 ± 3.20 (0.26 to 1.15)	0.002*
D (A.U.)	1.02 ± 0.16	1.01 ± 0.17	0.01 ± 0.16 (-0.01 to 0.03)	0.158
Stiffness ($N \cdot m^{-1}$)	479.13 ± 117.41	452.12 ± 95.85	27.01 ± 122.65 (10.11 to 43.90)	0.002*
EI (A.U.)	1.61 ± 0.97	1.49 ± 0.87	0.13 ± 1.22 (-0.04 to 0.29)	0.071
Achilles tendon				
FR (Hz)	35.93 ± 5.42	35.22 ± 5.34	0.71 ± 5.49 (-0.0. to 0.00)	0.098
D (A.U.)	0.64 ± 0.22	0.59 ± 0.17	0.04 ± 0.21 (0.01 to 0.04)	0.009*
Stiffness ($N \cdot m^{-1}$)	960.36 ± 154.71	955.61 ± 162.29	4.74 ± 149.97 (-0.02 to 0.02)	0.341
EI (A.U.)	1.66 ± 0.97	1.68 ± 0.99	-0.02 ± 1.07 (-0.01 to 0.00)	0.416

FR: oscillation frequency (Tone), D: logarithmic decrement (Elasticity), EI: elastography index; *significance level $p < 0.05$.

4. DISCUSSION

The main objectives of this study were to describe the structural and mechanical properties of the tendons in the lower limbs of senior badminton players (> 35 years) and to detect possible asymmetries in the patellar and Achilles tendons between the dominant and non-dominant lower limbs, caused by the continued practice of badminton. In this respect, reference values have been reported that are representative of senior badminton players and it has been found that the thickness and width of the Achilles tendon were greater on the non-dominant side, possibly due to the repeated concentric effort made during the last part of the movements that the non-dominant leg has to perform to propel the player towards the final zone of the stroke, adding the eccentric effort in the same region during the landing from the jumps (Fu et al., 2017), However, tone and stiffness were greater in the dominant patellar tendon, as most of the braking is done with the dominant leg, producing a greater eccentric force in the dominant leg, above all in the region of the quadriceps and hamstrings, in comparison with the non-dominant limb. These results suggest that the prolonged practice of badminton could affect the structure of the Achilles tendon and also the mechanical properties of the patellar and Achilles tendons; knowledge that could help coaches and trainers to adapt training sessions in order to reduce imbalance between the dominant and non-dominant lower limbs and the incidence of injuries in senior badminton players.

The characteristics of badminton that imply intermittent physical efforts and high demands of speed, coordination, changes of direction, jumps and one-sided activity, could be the reasons that explain the differences in the myotendinous structural adaptations that are caused by the sports practice (Couppe et al., 2008). The senior badminton players in our investigation showed bilateral differences in the structural characteristics of their Achilles tendons, revealing higher values for thickness (5.34 ± 19.90 %, $p = 0.027$) and width (1.57 ± 8.52 %, $p = 0.036$) in the non-dominant Achilles tendon in comparison with the dominant Achilles tendon. These differences could be caused by the repeated concentric efforts made by the non-dominant leg in the last part of the movements, using mainly the gastrocnemius and soleus to propel the player to the final zone for the stroke, adding the eccentric effort in the same region during the landing from the jumps (Fu et al., 2017). The beginning of practically all the movements is carried out with the main intervention of the non-dominant lower limb, with the intensity of the movement concentrated in the triceps surae. Moreover, the posture that is taken up on the backhand rear court especially when landing on one leg (the non-dominant leg) can cause the Achilles tendon to suffer greater tension as it absorbs the impact of the movement, and in the subsequent acceleration to the centre of the court. In the above-described situation the non-dominant lower leg is completely extended which means that practically all the load during the braking of the movement and the subsequent move to regain the centre of the court falls on the triceps surae and particularly on the Achilles tendon. The adaptation of the Achilles tendon to sport has already been studied in other sports like athletics, revealing greater values for thickness, width or CSA in comparison to that of non-athletes or sportsmen from non-impact sports like water polo (Magnusson & Kjaer, 2003; Wiesinger et al., 2016).

The data in our study did not show differences in the structural characteristics of the patellar tendon in the senior badminton players, which means that they are contrary to those presented by other authors (Bravo-Sánchez et al., 2019; Couppe et al., 2008; Couppe et al., 2013) who analysed athletes that showed a difference in strength between one side and the other of over 15%, due to the load induced by sport over several years. Couppe et al. (2008) in their study of badminton players and fencers, found greater values for the CSA in the dominant patellar tendon both in the distal (tibia) and in the proximal (patella) sections (dominant: 1.39 ± 0.11 cm^2 and 1.06 ± 0.07 cm^2 vs. non-dominant: 1.16 ± 0.07 cm^2 y 0.83 ± 0.04 cm^2) but did not find differences in the CSA between the dominant and non-dominant patellar tendons in the middle section (mid-point between the patella and the tibia) (dominant: 0.85 ± 0.05 cm^2 vs. non-dominant: 0.77 ± 0.03 cm^2, $p = 0.218$), which is the point that is nearest to the measurement point in our study (1 cm from the inferior edge of the patellar). Bravo-Sánchez et al. (2019) reported values 0.52 ± 0.60 cm^2 greater in the CSA of the dominant patellar tendon in elite badminton players (2.02 ± 0.64 cm^2 vs. 1.51 ± 0.42 cm^2; $p = 0.004$). Although other authors have found differences in the CSA of the dominant compared to the non-dominant patellar tendon, (Couppe et al., 2008) caused by the imbalance produced during the game, where the majority of the braking towards the net is done by the dominant leg which causes a greater eccentric force in this limb, in our study we did not find this difference. It should be borne in mind that the mentioned studies have analysed limited and very homogenous samples; all of them have analysed professional badminton players with a very high training and competitive load, who were at the peak of their sports careers and with a mean age which was much lower than that of our study (Bravo-Sánchez et al., 2019; Couppe et al., 2008; Couppe et al., 2013). In any case, further research is needed to help to justify these discrepancies.

The chronic adaptation to exercise in the mechanical properties of different tissues like stiffness, measured with the Myoton or sonoelastography, has been studied and used to describe the characteristics of tendons and muscles (Finnamore et al., 2019; Gavronski et al., 2007; Pozarowszczyk et al., 2017). Our data on the stiffness of the Achilles tendon (dominant: 960.36 ± 154.71 $N·m^{-1}$ vs. non-dominant: 955.61 ± 162.29 $N·m^{-1}$) are similar to those reported by other authors regarding elite football players (dominant: 1075.0 ± 100.8 $N·m^{-1}$ vs. non-dominant: 1031.0 ± 115.9 $N·m^{-1}$) and greater than those described in karatekas (dominant: 751.6 ± 123.5 $N·m^{-1}$ vs. non-dominant: 813.8 ± 134.6 $N·m^{-1}$) (Pozarowszczyk et al., 2017) or active subjects who presented values of 873 ± 72 $N·m^{-1}$ (Finnamore et al., 2019), 776.11 ± 71.70 $N·m^{-1}$ (Liu et al., 2018) y 771.0 ± 105.3 $N·m^{-1}$ (Schneebeli et al., 2020).

In our study the stiffness of the dominant patellar tendon was 4.41 ± 21.11 % higher than the non-dominant patellar tendon ($p = 0.002$). This study is one of the first to show a bilateral difference in the stiffness of the patellar tendon in athletes, in contrast to other investigations carried out with elite badminton players (dominant: 515.13 ± 180.50 $N·m^{-1}$ vs. non-dominant: 518.63 ± 168.63 $N·m^{-1}$), elite football players (dominant: 1138.0 ± 215.5 $N·m^{-1}$ vs. non-dominant: 1118.0 ± 199.1 $N·m^{-1}$), breakdancers (dominant: 1045 ± 202 $N·m^{-1}$ vs. non-dominant: 1084 ± 193 o con $N·m^{-1}$), or with physically active people (dominant: 902 ± 166 $N·m^{-1}$ vs. non-dominant: 862 ± 159 $N·m^{-1}$) which did not find bilateral differences (Bravo-Sánchez et al., 2019; Cristi-Sanchez et al., 2019; Young et al., 2018). The highest values found in the patellar tendon in the above-mentioned studies could be due to the fact that the subjects were elite athletes, and in our study, they were senior players (> 35 years) and both the training hours and loads are lower than in the general elite category. Furthermore, greater stiffness in tendons is related to a better performance in agility tests, changes of pace, sports with continual stretch-shortening cycles (which include speed, acceleration, running economy, vertical jump performance and strength) and speed/sprint tests (Pruyn et al., 2016) but at the same time the risk of musculotendinous injuries in tendons with these characteristics is greater due to the fact that the stiffness of the tendon makes it absorb less energy and increases the forces generated in the muscle (McHugh et al., 1999). In our study the badminton players, in spite of having a much older mean age than the athletes and physically active subjects mentioned in the cited studies (27.3 ± 2.9 years) (Young et al, 2018) had less stiffness in the patellar tendon which would make them less at risk for injury in this structure (McHugh et al., 1999; Witvrouw et al., 2004).

As well as the bilateral difference in the stiffness of the patellar tendon, differences were also found in the tone of the patellar tendon and the elasticity of the Achilles tendon, with higher values in the dominant than the non-dominant limb. Thus, the greater stiffness in the dominant patellar tendon, represented by higher values in the variables of stiffness and tone, would mainly be caused by the braking performed during the matches in approaches to the net by flexing the knee (by the action of the quadriceps and hamstrings), first eccentrically to brake the movement, and then concentrically to recover the position at the centre of the court. These movements are always made with the dominant leg and place this patellar tendon more at risk of injury than that of the non-dominant leg. In contrast, the Achilles tendon of the dominant leg revealed higher values of elasticity, which may be due to the fact that in this movement towards the net described above, the ankle is in extension with the shortened triceps surae playing a secondary role. Thus, in the case of badminton it is the Achilles tendon of the non-dominant leg that has to support the greater load during the match, as it is more important in the propulsion at the start of each movement and before the last step in approaches to the net, as well as in the impact absorption in the jumps.

It is worthy of mention that these differences in the mechanical properties of the tendons in both limbs were not supported by the EI measured with ultrasound sonoelastography. The results differ from those of other investigations which describe a correlation between both measuring systems, sonoelastography measured by ultrasound and myotonometry (Feng et al., 2018). Most of the research that used both methods were focused on sedentary subjects (Drakonaki et al., 2009; Feng et al., 2018) so that the special characteristics of the senior badminton players and their effect on the properties of the tendons could have affected the correlation of both devices. The reliability of the Myoton Pro and its lesser dependency on the examiner than the techniques with sonoelastrography strain or manual compression (Feng et al., 2018) lead us to suggest the use of the Myoton Pro by coaches and the rest of the players' staff who are not experts in imaging techniques. This study is one of the first to be carried out on senior badminton players, and thus, more research is needed to better understand the effect of prolonged badminton practice on the structural and mechanical properties of the patellar and Achilles tendons in senior badminton players (> 35 years) and those of other sports.

5. CONCLUSION

This paper describes the structural and mechanical properties of the tendons in the lower limbs of a representative sample of senior badminton players (> 35 years). The results show that the tendons of senior badminton players are different between the dominant and non-dominant lower limbs with regard to structural and mechanical properties. The thickness and width of the Achilles tendons were greater in the non-dominant limbs while the elasticity of the Achilles tendon and the tone and stiffness of the patellar tendon were greater in the dominant limb. No differences were found in the structure of the patellar tendon or in the sonoelastography variables of the analysed tendons. Therefore, these results suggest that the prolonged practice of badminton could indicate senior badminton players have a greater risk of injury in the patellar tendon in the dominant lower limb and in the Achilles tendon in the non-dominant lower limb. All these data can help coaches and trainers to adapt training sessions with the aim of reducing the incidence of injury in senior badminton players.

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