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Structural and mechanical properties of the Achilles tendon in senior badminton players: Operated vs. non-injured tendons

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ABSTRACT

Background: The aim of this study was to describe the differences in structural and mechanical properties between operated and non-injured Achilles tendons in senior badminton players who had had Achilles tendon surgery and had returned to play.
Methods: Eighteen players (age = 48.9(10.0)years), assigned to the unilateral Achilles tendon rupture group and 177 non-injured players (age = 55.4(9.4)years), assigned to the control group. A Logiq®S8 ultrasound was used to study tendon structure and elastography index values and a Myoton®PRO hand-held myotonometer was used to record the stiffness of the Achilles tendon.
Findings: In Achilles tendon rupture group, operated tendons showed higher values than non-injured ones in thickness (Operated = 9.03(2.67)mm vs. non-injured = 5.88(0.88)mm; $P < 0.001$), width (Operated = 18.44 (3.20)mm vs. non-injured = 16.80(1.97)mm; $P = 0.039$), cross sectional area (Operated = 140.33(60.29)mm^2 vs. non-injured = 74.40(17.09)mm^2; $P < 0.001$) and elastography index (Operated = 2.05(1.35)A.U. vs. non-injured = 1.47(0.62)A.U.; $P = 0.025$). The bilateral differences shown by the Achilles tendon rupture group were greater than the bilateral differences shown by the control group for thickness ($P < 0.001$), width ($P = 0.001$), cross sectional area ($P < 0.001$), tone ($P = 0.006$) and dynamic stiffness (Achilles tendon rupture group = 10.85 (23.90)N·m^{-1}. vs. control group = 0.18(18.83)N·m^{-1}; $P = 0.031$).
Interpretation: Surgery on the Achilles tendon and adaptation to the mobilisation and strength training during rehabilitation could provoke structural and mechanical differences compared to the non-injured tendon. Furthermore, the differences between both Achilles tendons in the Achilles tendon rupture group was higher than the asymmetry observed between dominant and non-dominant Achilles tendons in the control group. In addition, the higher logarithmic decrement values showed by non-injured tendons in the Achilles tendon rupture group could be a tendinous injury risk factor.

1. Introduction

Badminton is a popular racket sport, with high intensity demands during matches (Abian-Vicen et al., 2013). It has a lower injury incidence compared with contact sports although, due to the large number of players worldwide, a high number of injuries is recorded each year (Herbaut et al., 2018). Badminton requires jumps, lunges and quick changes in direction which provoke repetitive movements of the lower limb joints (Reeves et al., 2015). The badminton practice during many years provokes adaptations in the patellar and Achilles tendons (Boesen et al., 2011; Couppe et al., 2013) but no study was found which explains the effect of the return to badminton practice after Achilles tendon surgery.

Achilles tendon injuries have been divided into spontaneous ruptures and overuse injuries (Jarvinen et al., 2005). According to previous studies, one of the main causes of Achilles tendinopathy is the excessive overload which results in the degeneration of the Achilles tendon (Fahlstrom et al., 2002; Jarvinen et al., 2005). Therefore, problems with the Achilles tendon can be related to sports practice and over-exercising (Longo et al., 2009). The rupture of the Achilles tendon is one of the most severe injuries in badminton, and keeps players from sports participation for a long time because of the healing and recovery process

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(Huang et al., 2015). Furthermore the long immobilisation period reduces collagen synthesis/degradation (Geremia et al., 2015) and causes operated tendons to contain a greater proportion of weaker type III collagen, which decreases the tensile strength of operated tendons (Kannus et al., 1997). These changes that occur during the immobilisation process can affect the mechanical tendon properties as a whole (Kannus et al., 1997) and the demands of the sport could provoke differences in post-surgery tendon adaptations between athletes and sedentary people (Geremia et al., 2015; Zellers et al., 2016).

B-mode Ultrasound (US) is one of the most common techniques used to evaluate and measure the characteristics of tendon structure. In addition, ultrasound elastography (SE) allows a non-invasive assessment of tissue mechanical properties in resting conditions (Fletcher et al., 2010; Lerner et al., 1990). This method has been described in vitro (Lerner et al., 1990) and in real-time measurements as an imaging tool for estimating tissue strain distribution (Drakonaki et al., 2009). SE, based on tissue hardness, can be determined by applying a known pressure on the tissue under study (Park and Kwon, 2011). Based on the different biomechanical properties found between normal and pathologic tendons, SE can help us monitor pathologic or post-surgery conditions and tendinous adaptations to the return to play (Park and Kwon, 2011). Therefore, the elastic properties of tissues measured with SE are helpful in making a descriptive model of the mechanical properties of the Achilles tendon in badminton players who have undergone Achilles tendon surgery (Geremia et al., 2015; Tan et al., 2012).

In relation to mechanical properties of the Achilles tendon, stiffness describes the mechanical properties of the muscle-tendon unit and also of the free tendon structure regarding the storage and release of elastic energy in stretch-shortening cycle (SCC) activities (Murphy et al., 2003). High levels of stiffness have been related to superior performance in physical activities and sports with continuous SCCs, including speed, acceleration, running economy, vertical jump performance and strength (Pruyn et al., 2016), so stiffer tendons could facilitate enhanced performance in badminton players. Myotonometer measurement is a non-invasive technique based on the free oscillation theory which shows the possibility of measuring parameters such as dynamic stiffness and logarithmic decrement after a brief mechanical tap on the skin, which induces a damped or decaying natural oscillation of the tissue recorded by an acceleration sensor attached to the device's frictionless measuring mechanism (Ditroilo et al., 2011). Dynamic stiffness (N/m) assessed with the myotonometer has been used in different studies to characterise the behaviour of different musculoskeletal tissues (Schneebeli et al., 2020). Previous studies have shown a positive correlation between dynamic stiffness measured with a myotonometer and the rate of force development (Pruyn et al., 2016). In addition, dynamic stiffness values measured with a myotonometer can differentiate between dominant and non-dominant lower limbs (Cristi-Sanchez et al., 2019) and even between injured and non-injured tendons (Morgan et al., 2018). The studies that used myotonometric measurements have examined muscle (Gervasi et al., 2017; Wang, 2017) and tendon dynamic stiffness (Cristi-Sanchez et al., 2019; Schneebeli et al., 2020). Feng et al. (2018) have shown good reliability to assess Achilles tendon elastic properties, although more studies assessing Achilles tendon dynamic stiffness with a myotonometer are needed to fully understand the effect of surgery and return to play on the mechanical properties of Achilles tendons.

Despite the importance of Achilles tendon injury in badminton, the biomechanical properties of repaired tendons have not yet been compared with those non-injured tendons during return to play in badminton. Therefore, the aim of this study was to describe the differences in the structural and mechanical properties in operated and non-injured Achilles tendons of senior badminton players who had had unilateral Achilles tendon surgery and had returned to play.

2. Methods

2.1. Participants

One hundred and ninety-five senior badminton players, who participated in the European Senior Badminton Championship, volunteered to participate in this investigation. Participants were divided into two groups: a unilateral Achilles tendon rupture group (ATR group) ($n = 18$, age: 48.9 (10.0) years, height: 175.8 (11.8) cm, body mass: 77.9 (14.7) kg, percentage of fat: 14.7 (7.8) %, years of badminton practice: 33.3 (11.3) years, peak hours of training 11.1 (7.1) hours$\cdot$week^{-1}) and a control group ($n = 177$, age: 55.4 (9.4) years, height: 172.6 (9.9) cm, body mass: 74.3 (13.4) kg, percentage of fat: 15.2 (7.6) %, years of badminton practice: 33.0 (12.8) years, peak hours of training 9.8 (5.6) hours$\cdot$week^{-1}). The ATR group was composed of players who had previously suffered a complete mid-substance Achilles tendon rupture and had returned to play after tendon repair and rehabilitation. The sample size was previously calculated based on Geremia et al. (2015) who measured Achilles tendon stiffness to analyse the difference between operated and non-operated tendons. The minimal number of subjects required to attain a power of 0.9 and a bilateral alpha level of 0.05 was calculated to be 14. In selecting subjects for the ATR group, the inclusion criteria were to have sustained a rupture and repair greater than 5 years previously to permit healing, rehabilitation and remodelling required to return to play. The inclusion criteria of the controls were not to have any previous Achilles tendon rupture. Players with an injury or any pain that would prevent them from doing their usual sports practice and also those players with both Achilles tendons operated were excluded from the sample (Fig. 1).

All participants were informed about the purpose and procedures of the investigation and signed an informed consent before the start of the study. The study was approved by the Ethics Committee of Clinical Research at the Hospital Complex in Toledo (Spain) (number 72, dated 11/05/2017) according to the principles of the latest version of the Declaration of Helsinki.

All the players were examined with a Logiq® S8 (GE Healthcare, Milwaukee, WI) with a 5 to 15-MHz linear probe (ML6–15-D; GE Healthcare system), using grey scale US and SE. All of the exams, US and SE, were performed with a 10-MHz frequency of ultrasound, 30 mm in depth and 50 mm in length. The ultrasound device has a resolution of ~65 μm. Players were examined in a prone position with the foot hanging over the edge of the examination bed and in a neutral position (ankle joint dorsiflexion 0°) controlled by a goniometer and using a self-made ankle foot orthosis (Feng et al., 2018), and without gastrocnemius contraction. The mechanical properties of both Achilles tendons were also measured with a hand-held myotonometer Myoton® Pro (Myoton AS, Tallinn, Estonia). The US and SE exams were performed by the same radiologist (FJ), with more than 20 years' experience in musculoskeletal ultrasound examination. The MyotonPRO exams were also performed by an expert operator (ABS). The data were processed always by the same blinded researcher (PA).

2.2. Measurement of tendon structural properties using ultrasound

An ultrasound high resolution grey scale exam with B-mode was performed on both Achilles tendons. The tendons were scanned in the longitudinal and axial planes, taking care to avoid anisotropy. The thickness and fat layer of the tendon was measured 30 mm above the insertion of the Achilles tendon, in its free portion, and in the longitudinal plane. These measurements have previously shown acceptable reliability (Rasmussen, 2000). Furthermore, the CSA and the width of both tendons were measured at the same point on the axial plane. All images were analysed with Image J, 1.47 version (National Institute of Health, Maryland, USA) (Fig. 2).

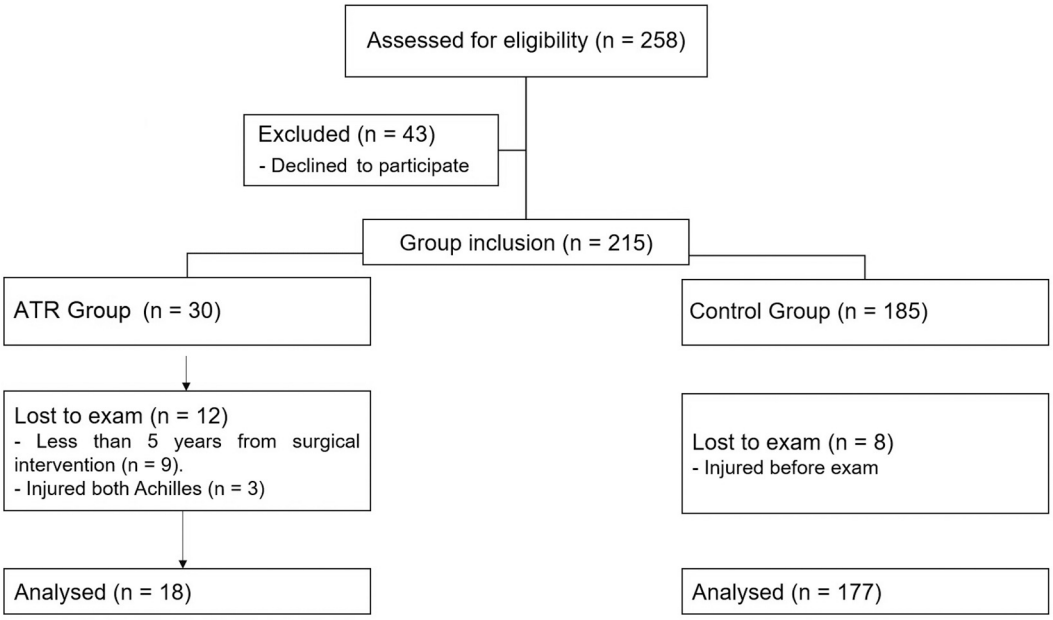

Fig. 1. Flow diagram. ATR Group = Achilles Tendon Rupture Group.

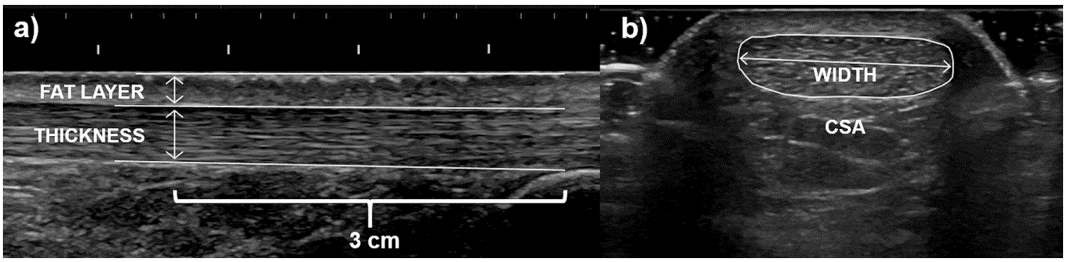

Fig. 2. Example of thickness, width and cross-sectional area measured on an ultrasound image. Tendon thickness was calculated as the distance between the deep and superficial aponeurosis. Width was calculated as the long distance between both sides of tendons. Cross sectional area (CSA) was calculated as the surface of the tendon in the axial plane. a) Longitudinal image; b) Transversal image.

2.3. Measurement of tendon mechanical properties using Elastography

SE was performed by applying light repetitive compression with the hand-held transducer. The elastogram appeared within a rectangular region of interest (ROI) as a translucent colour-coded real-time image superimposed on the B-mode image (Klauser et al., 2013). The tendon strain was measured using manually applied circular ROI measuring 4–5 mm in diameter (Drakonaki et al., 2009) and within the rectangular ROI. The colour-code indicated the strain of the tissues within the ROI, where red corresponded to soft elasticity, green and yellow indicated medium elasticity and blue indicated hard elasticity. The best cine image derived from at least three compression-relaxation cycles was used for the assessment of the elastography index (Klauser et al., 2013). The elastography index was calculated by comparing the Achilles tendon to the adjacent fat tissue (Turan et al., 2013) and was automatically calculated by the SE machine. The images that included a whole thickness of the Achilles tendon with the subcutaneous layer and calcaneus bone surface were selected. A higher value of elastography index is related to a higher stiffness level. For each participant, SE was performed in the longitudinal plane and was measured 30 mm above the insertion of the Achilles tendon (Fig. 3).

2.4. Measurement of tendon viscoelastic properties using the MyotonPRO

The Myoton®PRO measures the deformation properties of natural damped oscillations produced following a brief (15 ms) mechanical tap with a precompression of 0.18 N and an impulse of 0.40 N (total = 0.58 N) on the surface of the skin (Aird et al., 2012; Schneebeli et al., 2020). Computational software creates data on logarithmic decrement, tone (oscillation frequency) and dynamic stiffness of the underlying tissue, based on equations calculated from the acceleration of the testing probe during oscillations (Gavronski et al., 2007). The assessment of myotendinous viscoelastic properties with the MyotonPRO has shown good values of reliability and validity (Pruyn et al., 2016; Schneebeli et al., 2020). Logarithmic decrement was defined as the biomechanical property that characterises the ability of a tendon to recover its initial shape after a muscle contraction or the removal of an external force (i.e. inversely proportional to elasticity) (Gavronski et al., 2007). Oscillation frequency (Hz) shows the tone of the tendon in its testing state, which can be at rest without any muscle contraction or with an external force acting on it (Gavronski et al., 2007). Dynamic stiffness (N/m) is the biomechanical property of the tendon that explains the tendon resistance to an external force that deforms its initial shape (Gavronski et al., 2007). Three consecutive measurements were taken 30 mm above the insertion of the Achilles tendon.

2.5. Statistical analysis

The statistical analysis was performed with IBM SPSS Statistics 23.0 (SPSS, Chicago, Illinois). All data were expressed as mean and standard deviation. The data were tested for normality with a Kolmogorov–Smirnov test. Since the assumption of normality (all variables $P >$

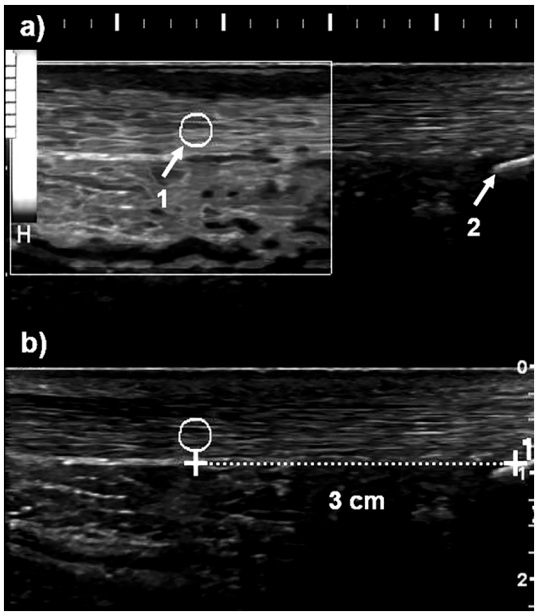

Fig. 3. Example of elastography index measurement on a sonoelastographic image. Tendon elastography index was calculated 30 mm from the calcaneus bone (1) with a circle area (2) inside the tendon. a) Colour map image of the Achilles tendon; b) B-Mode image of the Achilles tendon.

0.05) was verified, the tendon structural and mechanical properties were compared between the ATR group and control group using a two-way ANOVA. The factors were the group (ATR group and control group) and the side (operated and non-injured, dominant and non-dominant). Age, height, body mass, percentage of body fat, number of years of badminton practice and number of training hours at the peak of their careers were compared between the ATR group and control group using a Student's *t*-test for independent samples. A Student's t-test for independent samples was also employed to compare structural and mechanical properties of the non-injured tendon of the ATR group with dominant and non-dominant tendons of the control group. A probability level $p < 0.05$ was defined as statistically significant. The between-side comparison percentage difference was calculated for the ATR group as: 100% – ([non-injured / operated] · 100%); and for the control group as: 100% – ([non-dominant / dominant] · 100%) – used as a measure of symmetry (Niemelainen et al., 2011).

3. Results

No differences were found in the descriptive variables of both groups' characteristics: Age ($P = 0.134$), height ($P = 0.209$), body mass ($P = 0.285$), percentage of body fat ($P = 0.758$) number of years of badminton practice ($P = 0.940$) and number of training hours at the peak of their career ($P = 0.345$).

3.1. Tendon structure

Regarding the ATR group, bilateral differences were observed in the Achilles tendon structure. The thickness of the operated tendon was 30.1 (18.9) % greater than the non-injured tendon ($p < 0.001$) (Table 1). Furthermore, the operated tendon showed higher values in width 6.8 (18.0) % ($p = 0.039$) and CSA 39.0 (24.2) % ($P < 0.001$) than the non-injured tendon (Table 1). No differences were found in the fat layer ($P = 0.229$) between operated and non-injured Achilles tendons (Table 1).

Bilateral differences were also observed in the Achilles tendon structure for the control group. The thickness in the non-dominant tendon was 5.3 (19.9) % greater than the dominant tendon ($P = 0.006$). Furthermore, the non-dominant tendon showed higher values in width 1.6 (8.5) % ($P = 0.036$) than the dominant tendon. No differences were found in CSA ($P = 0.472$) or in the fat layer ($P = 0.453$) between dominant and non-dominant Achilles tendons.

Table 1
Structural characteristic results measured in senior badminton players (mean ± standard deviation of operated and non-injured and, dominant and non-dominant tendons).

	ATR Group		Control Group		% Δ [IC 95%]
	Non-injured	Operated	Dominant	Non-dominant	
Thickness (mm)	5.88 (0.88)	9.03 (2.67)	5.59 (1.18)	5.79 (1.10)	
% Δ [IC 95%]	30.14 (18.90) [−0.44 to −0.19]		5.34 (19.90) [−0.01 to 0.01]		48.82 (5.73) [37.52 to 60.13]
Width (mm)	16.80 (1.97)	18.44 (3.23)	16.58 (1.87)	16.78 (1.82)	
% Δ [IC 95%]	6.78 (18.03) [−0.35 to 0.02]		1.57 (8.52) [−0.04 to 0.00]		9.30 (2.52) [4.32 to 14.28]
CSA (mm^2)	74.44 (17.09)	140.33 (60.29)	79.31 (20.82)	80.36 (20.83)	
% Δ [IC 95%]	38.97 (24.19) [−0.95 to −0.37]		2.24 (19.27) [−0.02 to 0.02]		95.04 (8.13) [79.01 to 111.08]
Fat Layer (mm)	1.67 (0.29)	1.56 (0.56)	1.65 (0.49)	1.65 (0.48)	
% Δ [IC 95%]	19.05 (40.98) [−0.02 to 0.04]		3.06 (25.03) [−0.01 to 0.00]		−4.93 (6.96) [−18.66 to 8.79]

CSA: cross sectional area. ATR: Achilles tendon rupture.

The ATR group exhibited larger differences between operated and non-injured lower limbs in structural characteristics than the control group between dominant and non-dominant limbs for thickness ($P < 0.001$), width ($P = 0.001$) and CSA ($P < 0.001$). No differences were found between the non-injured tendon of the ATR group compared to dominant and non-dominant tendons for thickness ($P = 0.205$), width ($P = 0.655$), CSA ($P = 0.272$) and fat layer ($P = 0.765$). (Table 1).

3.2. Tendon mechanical properties

Elastography index was a 5.3 (59.9) % higher in operated tendon than non-injured tendon values ($P = 0.047$) for the ATR group. No differences were described for this variable in the control group ($P = 0.452$) (Table 2).

Regarding mytonometric variables in the ATR group, operated tendons showed a 6.9 (16.0) % higher value in tone than non-injured tendons ($P = 0.025$) but no differences were found in logarithmic decrement ($P = 0.152$) and dynamic stiffness ($P = 0.067$). For the control group, the dominant lower limb showed a 1.5 (16.7) % higher tone than the non-dominant tendon ($P = 0.047$). Also, the dominant lower limb tendon showed 1.7 (30.9) % higher values than the non-dominant tendon ($P = 0.002$) in logarithmic decrement. No differences were found in dynamic stiffness ($P = 0.353$) (Table 2).

The ATR group exhibited larger differences between the operated and non-injured lower limbs in mechanical properties than the control group between dominant and non-dominant limbs for elastography index ($P = 0.036$), tone ($P = 0.006$) and dynamic stiffness ($P = 0.031$). The non-injured tendons of the ATR group showed higher logarithmic decrement values compared to the dominant tendon ($P = 0.041$) and non-dominant tendon ($P = 0.010$) in the control group. No differences were found in the non-injured tendon of the ATR group compared to dominant and non-dominant tendons for dynamic stiffness ($P = 0.105$), tone ($P = 0.411$) and elasticity index ($P = 0.235$). (Table 2).

Table 2
Mechanical property results measured in senior badminton players (mean ± standard deviation of operated and non-injured, and dominant and non-dominant tendons).

	ATR Group		Control Group		% Δ [IC 95%]
	Non-injured	Operated	Dominant	Non-dominant	
FR (Hz)	34.53 (5.45)	37.41 (5.21)	35.87 (5.39)	35.17 (5.30)	
% Δ [IC 95%]	6.90 (15.97) [−4.96 to −0.48]		1.51 (16.72) [0.01 to 1.39]		11.81 (4.23) [3.46 to 20.15]
D (A.U.)	0.80 (0.29)	0.73 (0.24)	0.64 (0.22)†	0.59 (0.17)†	
% Δ (IC 95%)	14.65 (36.49) [−10.19 to 10.31]		1.66 (30.90) [0.02 to 0.07]		1.27 (8.12) [−14.75 to 17.29]
Stiffness ($N \cdot m^{-1}$)	875.00 (193.03)	932.35 (104.80)	958.61 (154.26)	954.30 (161.16)	
% Δ (IC 95%)	6.45 (17.13) [−114.19 to 5.85]		0.19 (19.10) [−14.55 to 23.17]		10.67 (4.90) [1.00 to 20.33]
Elastography Index (A.U.)	1.47 (0.62)	2.05 (1.35)	1.67 (0.97)	1.68 (0.99)	
% Δ (IC 95%)	5.27 (59.94) [−1.15 to −0.01]		16.45 (72.47) [−0.14 to 0.12]		39.84 (19.10) [2.17 to 77.50]

ATR: Achilles tendon rupture; FR: Frequency; D: Logarithmic Decrement; † differences from non-operated tendon of ATR group; significant criteria $p < 0.05$.

4. Discussion

The most important finding of this study was that the ATR group showed a significant difference between operated and non-injured tendons after returning to play and at least five years after the surgical repair. The purpose of this study was to describe the differences in structural and mechanical properties of the Achilles tendon between operated and non-injured tendons in senior badminton players who had had Achilles tendon surgery and had returned to play. Significant differences between the non-injured tendon and the operated tendon were found in thickness, width, CSA, tone and elastography index for the ATR group. Also, this group showed higher asymmetry in mechanical variables (operated vs. non-injured tendons) than results shown by control group (dominant vs. non-dominant tendons). Therefore, the results suggest that the rupture and repair of the Achilles tendon, despite the healing, rehabilitation and remodelling time, could affect its structure and mechanical properties.

The Achilles tendon injury is one of the most common injuries in sports demanding running and jumping (Houshian et al., 1998). Badminton practice involves high physical demands with quick changes of direction, speed and coordination and, this characteristics could be the reason why most badminton injuries are chronic overuse injuries (Jorgensen and Winge, 1987), such as tendinopathy and rupture of the Achilles tendon (Fahlstrom et al., 2002). After Achilles tendon rupture, around 60% of basketball players returned to their pre-injury level (Amin et al., 2013) and, few differences in outcome variables were reported between surgical and non-surgical repair for Achilles tendon rupture after 12 months of follow up (Olsson et al., 2013). In addition, Eliasson et al. (2018) concluded that at least 12 months are necessary to recover full function after an Achilles tendon rupture, regardless of the treatment. The rupture and the following surgery cause changes in tendon structure such as thickness (Geremia et al., 2015). These changes in tendon thickness seem to be present several months even years post-surgical repair, and our results agree with the study of Maffulli et al. (2003), indicating that the operated tendon is structurally different. In addition, our results showed that CSA was 39.0 (24.2) % larger in the operated tendon than the non-injured one. This percentage of difference is lower compared to other research which showed values of over 110% difference (Geremia et al., 2015) measured in sedentary people. This could be the result of the return to play in badminton, that favours the values of operated tendons becoming more similar to non-injured tendons than the data described in other situations.

The operated tendon is characterised by a round irregular area with mixed echogenicity and increased size (Tan et al., 2012). Furthermore, repair of acute injuries usually affects the composition of tendons, increasing synthesis of type III collagen in relation to type I collagen synthesis, which might stiffen the tendon (Tan et al., 2012). In this line of thought, tendon injury, whether it is rupture or tendinopathy, affects tendinous mechanical properties and usually decreases mechanical stiffness and Young's modulus in the affected Achilles tendons when they are estimated from tendon CSA and tendon force (Geremia et al., 2015). Dynamic stiffness measured with the MyotonPRO describes the tendon resistance to an external force that deforms its initial shape in resting conditions without considering tendon CSA or tendon force. Therefore, an increase in the synthesis of type I collagen due to tendon damage, could lead to an increase in dynamic stiffness associated with the increase of the tendinous tissue resistance to external forces. The differences found between operated and non-injured tendons in the ATR group of our study were greater than the differences between dominant and non-dominant Achilles tendons in elastography index, tone and dynamic stiffness values shown by players in the control group. Returning to play and keeping ongoing competitive sports participation could reduce these differences between groups and help the athletes to regain pre-injury sports performance (Zellers et al., 2016) but no effect was described in our study. More longitudinal research is necessary to ascertain how much a return to play affects mechanical properties of the tendon a long time after surgery and how many years are necessary to get similar mechanical properties as non-injured athletes, if this is possible.

Non-injured Achilles tendons in the ATR group showed higher logarithmic decrement values compared to both tendons in the control group, dominant and non-dominant. Myotonometry is a valid tool for the assessment of myofascial pain and injury risk (Jimenez-Sanchez et al., 2018). Therefore, higher values of the logarithmic decrement may indicate that it is a predisposing factor of Achilles pathology as occurs with lower values of CSA (Couppe et al., 2013). Finally, these results differ from those of the research which describe a correlation between both measurements, SE and mytonometer (Feng et al., 2018). Most of the research done with both methods, was focused on sedentary people (Drakonaki et al., 2009; Feng et al., 2018) so the special characteristics of badminton players and their effects on tendon properties could influence the correlation of both tools.

This study has several limitations. First, the time to return to play since surgery was not taken into account, only as an excluding criterion. Second, SE is a US-based technique therefore it has the limitations of all US-based methods such as relatively high operator dependency. To avoid these limitations, a highly experienced SE examiner performed the SE exams. Moreover, the method of repair was not recorded to qualify the operated tendons, although all of ATR group participants suffered unilateral rupture of the Achilles tendon. Also, future studies are necessary to clarify the effect of return to play on properties of operated tendons and how many years would be necessary to obtain normal differences between both tendons, operated and non-injured.

5. Conclusion

In conclusion, operated Achilles tendons were thicker, wider, stiffer and with greater CSA than non-injured Achilles tendons after five years of returning to play. The differences in the ATR group tendons showed an asymmetric pattern between operated and non-injured tendons greater than the asymmetry shown by non-injured players. The higher

logarithmic decrement values showed by non-injured tendons in the Achilles tendon rupture group could be a tendinous injury risk factor. Further studies are warranted to understand the difference between Achilles operated and recovered tendons in badminton players and sedentary people regarding structural and mechanical properties.

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Declaration of Competing Interest

The authors declare that they have no conflict of interest.

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