Effects of Training Load and Leg Dominance on Achilles and Patellar Tendon Structure

Alireza Esmaeili, Andrew M. Stewart, William G. Hopkins, George P. Elias, and Robert J. Aughey

Purpose: Detrimental changes in tendon structure increase the risk of tendinopathies. The aim of this study was to investigate the influence of individual internal and external training loads and leg dominance on changes in the Achilles and patellar tendon structure. **Methods:** The internal structure of the Achilles and patellar tendons of both limbs of 26 elite Australian footballers was assessed using ultrasound tissue characterization at the beginning and the end of an 18-wk preseason. Linear-regression analysis was used to estimate the effects of training load on changes in the proportion of aligned and intact tendon bundles for each side. Standardization and magnitude-based inferences were used to interpret the findings. **Results:** Possibly to very likely small increases in the proportion of aligned and intact tendon bundles occurred in the dominant Achilles (initial value 81.1%; change, $\pm 90\%$ confidence limits 1.6%, $\pm 1.0\%$), nondominant Achilles (80.8%; 0.9%, $\pm 1.0\%$), dominant patellar (75.8%; 1.5%, $\pm 1.5\%$), and nondominant patellar (76.8%; 2.7%, $\pm 1.4\%$) tendons. Measures of training load had inconsistent effects on changes in tendon structure; eg, there were possibly to likely small positive effects on the structure of the nondominant Achilles tendon, likely small negative effects on the dominant Achilles tendon, and predominantly no clear effects on the patellar tendons. **Conclusion:** The small and inconsistent effects of training load are indicative of the role of recovery between tendon-overloading (training) sessions and the multivariate nature of the tendon response to load, with leg dominance a possible influencing factor.

Keywords: tendinopathy, UTC, ultrasound, football, recovery

Tendons transfer forces from muscles to bones to facilitate movement. Tendon properties change in response to forces applied to the tendon through training¹ and detrimental changes in tendon structure are associated with increased risk of tendinopathies.² Tendon stiffness, elastic modulus, and cross-sectional area are measures of tendon mechanical, material, and (macro)morphological properties, respectively, which generally increase after controlled episodes of increased loading.¹ Little is known about changes in the internal tendon structure in the form of fibrillar alignment (micro-morphology) in response to training.

Traditional assessment of the internal tendon structure using ultrasound imaging requires manual tracking of the ultrasound probe. This approach along with the subjective and qualitative interpretation of the ultrasound images does not allow for quantification of subtle changes in the tendon structure.^{1,2} Ultrasound tissue characterization (UTC) is a novel approach that overcomes these limitations by using an automatic ultrasound-probe-tracking device and dedicated image analyzing algorithms.³ The tracking device standardizes the transducer tilt, angle, focus, gain, and depth.^{3,4} A software reconstructs and analyses a 3-dimensional image of the tendon and quantifies the internal tendon structure based on fibrillar alignment.³

A recent UTC study reported improved fibrillar alignment in the right Achilles tendons of elite Australian football league (AFL) players over the preseason,⁵ but individual training loads were not quantified, and the influence on changes in tendon micromorphology is currently unknown. The reported asymmetries between the dominant and nondominant Achilles and patellar tendons in

stiffness, elastic modulus, and cross-sectional area⁶⁻⁸ also raise the question of the influence of leg dominance on changes in the tendon fibrillar alignment in response to training. The aim of this study was to investigate the influence of training load and leg dominance on changes in the Achilles and patellar tendon structure.

Methods

Subjects

Thirty-seven players of 1 elite Australian football club agreed to participate in the study. Eleven of the players sustained injuries that resulted in more than 1 week of modified training during the study period and were subsequently excluded from the study (none were due to Achilles or patellar tendon injuries). The remaining 26 players (age 23.7 ± 3.7 y) were included in the data analysis. None of the included players had a history of Achilles or patellar tendon injury in the preceding 12 months to data collection.

Design

In this prospective cohort study, the Achilles and patellar tendon structure of both legs of the participants were examined using UTC at the beginning and the end of an 18-week preseason training. Internal and external training loads of individual players were quantified for the period between the 2 UTC sessions.

Methodology

Ultrasound Tissue Characterization. The UTC equipment and scanning protocols were as previously described.⁹ An automatic tracking device moved the ultrasound transducer along the length

The authors are with the Inst of Sport, Exercise and Active Living, Victoria University, Melbourne, Australia. Address author correspondence to Robert Aughey at Robert.Aughey@vu.edu.au.

of the tendon capturing an ultrasound image every 0.2 mm. Layers of ultrasound images were then combined in proprietary software (UTC2010, UTC Imaging) to form a 3-dimensional data block of the tendon. Algorithms within the software package analyzed the stability of brightness in each pixel across contiguous layers. The structure of the scanned tendon was then quantified as relative percentages of 4 distinct echo-types which have previously been verified against histological specimens.³ Echo-type I corresponds with intact, aligned, and continuous bundles; echo-type II represents less continuous, less integer, and waving bundles; echo-type III relates to disorganized and fibrillar tissue; and echo-type IV characterizes amorphous matrix with loose fibrils, cells, or fluid.³ Changes in the echo-types over the preseason were analyzed with increased echo-type I signifying improvements in tendon structure.⁵

Training Load. The internal training load, monotony, and strain for all training sessions were calculated for individual players using the session rating of perceived exertion (sRPE) method.¹⁰ A typical training week consisted of 3 field-training, 4 weight-training, 3 aerobic-training, 2 recovery, and 1 other conditioning sessions. Two to three days of reduced loading were planned between the days with high training loads. The general structure of preseason involved a controlled increase in training load followed by a period of relatively reduced loading (weekly loads similar to the competition period) and 4 preseason matches toward the end. Indeed some session types that involve high impact weight bearing or lower body weight training, apply larger forces to the Achilles and patellar tendons compared with other sessions (eg, field > recovery); however, since the exact differences are unknown, all session types were pooled to calculate the total individual internal training loads. The external training load was quantified using global positioning system (GPS)/accelerometer units (Optimeye S5, Catapult Innovations, Australia) for every field-training session (including the preseason matches). Total distance covered, Player Load, and the high-intensity-running (HIR) distance (>4.17 m/s) were extracted from the software (Sprint v5.1.3, Catapult Innovations, Australia).^{11,12}

Statistical Analysis

Data were analyzed using a custom Microsoft Excel spreadsheet.¹³ The modifying effects of training load on changes in tendon structure were estimated by including each measure separately as a linear covariate. The effects of training load were calculated for a 2-SD increase in the load.¹⁴ Standardization and magnitude-based inferences with 90% confidence limits were used to describe and interpret the results.¹⁴ Thresholds for interpreting the standardized change/effect (ES) were as follows: <0.2, trivial; 0.2 to <0.6, small; 0.6 to 1.2, moderate; >1.2, large.¹⁴ The chances of true change/effect (greater than the smallest worthwhile change/effect) were calculated and expressed qualitatively as follows: <0.5%, most unlikely; 0.5% to <5%, very unlikely; 5% to <25%, unlikely; 25% to <75%, possibly; 75% to <95%, likely; 95% to <99.5%, very likely; >99.5%, most likely. The true change/effect was assessed as unclear when the chances of positive and negative change/effect were both >5%.¹⁴

Results

Achilles and patellar tendons of both sides showed possibly to very likely small improvements (increases in echo-type I) over the training period (Figure 1). Increased echo-type I coincided with decreases in echo-type II and predominantly trivial or unclear

changes in echo-type III and echo-type IV (Figure 1) and as a result, all further analysis focused on changes in echo-type I.

There were no clear differences between the baseline values of the 2 sides for either the Achilles (ES 0.09; 90% confidence limits ± 0.34) or patellar (-0.21 ; ± 0.41) tendons. The improvement in the structure of the dominant Achilles tendon was possibly larger than the nondominant side (0.2; ± 0.32). No clear differences were found between the improvements in the patellar tendons of the 2 sides (-0.1 ; ± 0.35).

Training load (Table 1) had mostly clear but opposite effects on changes in the Achilles tendon structure of the 2 sides. Player Load, total distance, and HIR had likely small negative effects on the dominant Achilles tendon while the effects for the sRPE, monotony, and strain were unclear (Figure 2[A]). Player Load, sRPE, and strain had possibly to likely positive effects on the nondominant Achilles tendon while the effects for the total distance, HIR, and monotony were unclear (Figure 2[A]). There were likely to very likely moderate differences between the Achilles tendons of the 2 sides in the effects of various measures of training load.

Monotony and HIR were the only measures that had clear possibly small positive effects on the changes in the nondominant patellar tendon structure. All other measures had unclear effects on the patellar tendons of both sides (Figure 2[B]).

Discussion

The structure of the Achilles and patellar tendons of both sides improved over the preseason training period while individual training loads had small and inconsistent effects on the changes in tendon structure. The effects were mostly negative on the dominant Achilles tendon, mostly positive on the nondominant Achilles tendon, and mostly unclear on the patellar tendons of both sides.

Detrimental changes in the normal tendon structure induced by training, are proposed to fall on a continuum that ranges from reactive tendinopathy to tendon disrepair and eventually degenerative tendinopathy.¹⁵ An episode of acute tendon overloading elicits a proliferative response in the tenocytes and the extra cellular matrix that drives the tendon forward on the pathology continuum.¹⁵ On the other hand, episodes of reduced loading (recovery) negate such detrimental changes and allow the tendon structure to return back to normal.¹⁵ Detrimental changes in the Achilles tendon structure that are induced by an AFL match, return to baseline within four days.⁴ The observed small and inconsistent effects of training load in the current study indicate that the amount of training load is not the only driver of the changes in tendon structure over the preseason and the recovery of tendon structure before the next overloading sessions is a key factor. The Achilles and patellar tendons of AFL players can tolerate high training loads, within the range quantified in this study, provided enough recovery has occurred between 2 consecutive tendon-overloading sessions. Inadequate recovery between training sessions will likely result in reduced proportions of echo-type I, increases in echo-type II and in more severe/chronic cases increases in echo-types III and IV.

The improvement in the right Achilles tendons of a group of participants from another AFL club (6.1% increase in echo-type I)⁵ was considerably larger than the observed improvements in the current study (1.6% for the dominant and 0.9% for the nondominant Achilles tendons) despite the similarities between the two studies in participants' age and athletic level, training period, UTC equipment, and scanning protocols. Differences between the two clubs in training parameters as well as periodization and recovery

Figure 1 — Tendon structure at the start and the end of preseason. (A) Echo-type I, (B) echo-type II, (C) echo-type III, (D) echo-type IV, (E) estimated change in the 4 echo-types over the preseason. Brackets contain the raw change (%) ± 90% confidence limits. Abbreviations: D dominant, N nondominant. ↑small increase, ↓small decrease, ↓↓moderate decrease, ↔trivial change, # unclear change, *possibly, **likely, ***very likely, ****most likely.

strategies may have contributed to the differences in the magnitude of findings and further supports the discussed importance of these factors on changes in tendon structure. The abovementioned study excluded players with any training modification which could have also contributed to their larger magnitude of improvement as well as a higher baseline value for echo-type I (83.2%) compared with the current study (81.1% and 80.8%). Analysis of monotony and strain in the current study could not reflect the role of weekly training periodization as they were averaged for the 18 weeks of preseason. A weekly repeated measurement of tendon structure modeled against weekly measures of training load may provide a better estimate of the effects of training parameters and periodization on changes in tendon structure.

Leg dominance affected the amount of change in tendon structure, as well as the effects of training load, for the Achilles

tendon but not for the patellar tendon. Discrepancies between the Achilles tendons of the 2 sides may have arisen from the slightly different loads that go through these tendons due to sport-specific activities. Activities such as the single-leg weight-bearing phase of kicking and rapid push-off at the beginning of acceleration and change of direction are often performed with the nondominant side and exert large forces on the nondominant Achilles tendon,^{16–18} which could have contributed to the observed differences between the 2 sides. The positive effect of training load on the nondominant Achilles tendon may be the result of its long-term exposure to such larger forces and its subsequent improved adaptive capacity for a given load compared with the dominant side. Asymmetries in the elastic modulus and cross-sectional area of the dominant and nondominant Achilles tendons have been reported^{6,7} and we show that asymmetries also exist in the response to training

Table 1 Average Weekly Training Loads and the Between-Subjects Variability for the Period Between the 2 Ultrasound Tissue-Characterization Sessions

Measure of training load	Mean $\pm$ SD	Range
sRPE (AU)	2212 $\pm$ 190	1855–2595
Total distance (km)	19.1 $\pm$ 1.8	16.1–22.7
Player Load (AU)	1751 $\pm$ 208	1453–2200
High-intensity running (km)	5.1 $\pm$ 0.8	3.6–6.6
Monotony (AU)	0.89 $\pm$ 0.03	0.84–0.97
Strain (AU)	2281 $\pm$ 272	1808–2914

Abbreviations: AU, arbitrary units; sRPE, session rating of perceived exertion.

and the effects of training load at the micromorphological level. The observed opposite effects of training load on the Achilles tendons of the dominant and nondominant sides warrant further investigation into consideration of leg dominance in devising load management strategies for players who are at a higher risk of developing tendinopathies.

Practical Applications

Regular assessment of tendon structure may flag maladaptation to training in elite footballers.

Conclusions

The micromorphology (fibrillar alignment) of Achilles and patellar tendons of AFL players improved over the preseason training period. The small and inconsistent effects of training load are indicative of the role of recovery between tendon-overloading (training) sessions and the multivariate nature of the tendon response to load with leg dominance a possible influencing factor.

Acknowledgments

The authors acknowledge all the staff and players at the Western Bulldogs Football Club for their kind assistance with conducting this study. This study was funded by Victoria University and the Western Bulldogs Football Club. Alireza Esmaili is a recipient of a postgraduate research scholarship from Victoria University.

References

- Wiesinger H-P, Kösters A, Müller E, Seynnes OR. Effects of increased loading on in vivo tendon properties: a systematic review. *Med Sci Sports Exerc.* 2015;47(9):1885–1895. [PubMed doi:10.1249/MSS.0000000000000603](#)
- Docking SI, Ooi CC, Connell D. Tendinopathy: is imaging telling us the entire story? *J Orthop Sports Phys Ther.* 2015;45(11):842–852. [PubMed doi:10.2519/jospt.2015.5880](#)
- van Schie HT, de Vos R-J, de Jonge S, et al. Ultrasonographic tissue characterisation of human Achilles tendons: quantification of tendon structure through a novel non-invasive approach. *Br J Sports Med.* 2010;44(16):1153–1159. [PubMed doi:10.1136/bjsm.2009.061010](#)
- Rosengarten SD, Cook JL, Bryant AL, Cordy JT, Daffy J, Docking SI. Australian football players' Achilles tendons respond to game loads within 2 days: an ultrasound tissue characterisation (UTC) study. *Br J Sports Med.* 2015;49(3):183–187. [PubMed doi:10.1136/bjsports-2013-092713](#)
- Docking SI, Rosengarten SD, Cook JL. Achilles tendon structure improves on UTC imaging over a 5-month pre-season in elite Australian football players. *Scand J Med Sci Sports.* 2016;26(5):557–563. [PubMed doi:10.1111/sms.12469](#)
- Bohm S, Mersmann F, Marzilger R, Schroll A, Arampatzis A. Asymmetry of Achilles tendon mechanical and morphological properties between both legs. *Scand J Med Sci Sports.* 2015;25(1):e124–e132. [PubMed doi:10.1111/sms.12242](#)
- Pang BS, Ying M. Sonographic measurement of Achilles tendons in asymptomatic subjects variation with age, body height, and dominance of ankle. *J Ultrasound Med.* 2006;25(10):1291–1296. [PubMed doi:10.7863/jum.2006.25.10.1291](#)
- Couppé C, Kongsgaard M, Aagaard P, et al. Habitual loading results in tendon hypertrophy and increased stiffness of the human patellar

Figure 2 — Effects of training load on (A) Achilles and (B) patellar tendon structure: Estimated change in echo-type I for a 2-SD increase in training load. Brackets contain the estimated raw change (%) $\pm$ 90% confidence limits. Notes: ↑small positive effect, ↓small negative effect, #unclear effect, *possibly, **likely. Abbreviations: sRPE, session rating of perceived exertion, HIR, high-intensity running.

- tendon. *J Appl Physiol*. 2008;105(3):805–810. [PubMed doi:10.1152/japplphysiol.90361.2008](#)
9. Docking SI, Cook JL. Pathological tendons maintain sufficient aligned fibrillar structure on ultrasound tissue characterization (UTC). *Scand J Med Sci Sports*. 2016;26(6):675–683. [PubMed](#)
 10. Foster C, Florhaug JA, Franklin J, et al. A new approach to monitoring exercise training. *J Strength Cond Res*. 2001;15(1):109–115. [PubMed](#)
 11. Boyd LJ, Ball K, Aughey RJ. Quantifying external load in Australian football matches and training using accelerometers. *Int J Sports Physiol Perform*. 2013;8(1):44–51. [PubMed doi:10.1123/ijsspp.8.1.44](#)
 12. Aughey RJ. Australian football player work rate: evidence of fatigue and pacing? *Int J Sports Physiol Perform*. 2010;5(3):394–405. [PubMed doi:10.1123/ijsspp.5.3.394](#)
 13. Hopkins WG. Analysis of a post-only crossover trial, with adjustment for a predictor. *Sportscience*. 2006;10:46–50.
 14. Hopkins WG, Marshall S, Batterham A, Hanin J. Progressive statistics for studies in sports medicine and exercise science. *Med Sci Sports Exerc*. 2009;41(1):3–13. [PubMed doi:10.1249/MSS.0b013e31818cb278](#)
 15. Cook JL, Purdam CR. Is tendon pathology a continuum? A pathology model to explain the clinical presentation of load-induced tendinopathy. *Br J Sports Med*. 2009;43(6):409–416. [PubMed doi:10.1136/bjism.2008.051193](#)
 16. Maffulli N. Current concepts review—rupture of the Achilles tendon. *J Bone Joint Surg Am*. 1999;81(7):1019–1036. [PubMed doi:10.2106/00004623-199907000-00017](#)
 17. Clagg SE, Warnock A, Thomas JS. Kinetic analyses of maximal effort soccer kicks in female collegiate athletes. *Sports Biomech*. 2009;8(2):141–153. [PubMed doi:10.1080/14763140902752106](#)
 18. Ball K. Loading and performance of the support leg in kicking. *J Sci Med Sport*. 2013;16(5):455–459. [PubMed doi:10.1016/j.jsams.2012.10.008](#)