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Quantification of Achilles and patellar tendon structure on imaging does not enhance ability to predict self-reported symptoms beyond grey-scale ultrasound and previous history

Sean I. Docking[a,*], Ebonie Rio[a], Jill Cook[a], David Carey[a], Lauren Fortington[a,b]

[a] La Trobe Sports and Exercise Medicine Research Centre, La Trobe University, Australia
[b] Faculty of Science and Technology, Federation University Australia, Australia

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ABSTRACT

Background: Tendon pathology on imaging has been associated with an increased risk of developing symptoms. This evidence is based on classifying the tendon as normal or pathological. It is unclear whether the extent of tendon pathology is associated with the development or severity of symptoms.
Objectives: To investigate whether the presence and extent of tendon pathology on ultrasound tissue characterisation (UTC), or a previous history of symptoms, were associated with the development of symptoms over a football season.
Methods: 179 male Australian football players underwent UTC imaging of their Achilles and/or patellar tendon at the start of the pre-season. Players completed monthly OSTRC overuse questionnaires to quantify the presence and severity of Achilles and/or patellar tendon symptoms. Risk factor analysis was performed to identify associations between imaging and the development of symptoms.
Results: A pathological Achilles tendon increased the risk of developing symptoms (RR = 3.2, 95%CI 1.7–5.9). Conversely, a pathological patellar tendon was not significantly associated with the development of symptoms (RR = 1.8, 95%CI 0.9–3.7). Quantification of tendon structure using UTC did not enhance the ability to identify athletes who developed symptoms. Previous history of symptoms was the strongest predictor for the development of symptoms (Achilles RR = 3.0 95%CI 1.8–4.8; patellar RR = 3.7 95%CI 2.2–6.1).
Conclusion: Tendon pathology was associated with the development of self-reported symptoms; however previous history of symptoms was a stronger risk factor. The extent of disorganisation quantified by UTC should not be used as a marker for the presence or severity of current and future symptoms.

1. Introduction

The limited relationship between tendon pathology and the presence of symptoms has become clear in the last few years. Tendon pathology can exist in the absence of symptoms, and the source of nociception is unknown.[1] Up to 30% of the population have asymptomatic pathological changes,[2–4] which appear to be induced by chronic loading of the tendon.[5–7] While pathological changes observed on imaging are not directly related to the presence or development of symptoms, recent evidence suggests that imaging may have a role in injury screening.[2,8,9]

A recent systematic review demonstrated that pathology observed on imaging was associated with an increased risk of developing symptoms.[10] Based on the meta-analysis, people with a pathological Achilles tendon were 7-times more likely to develop symptoms, while people with a pathological patellar tendon were 4-times more likely to develop symptoms. Although ultrasound (US) imaging may have a role in the prediction of future symptoms, the clinical importance of these findings is unclear as ~79% of abnormal tendons remained asymptomatic.[10]

Whether the severity of pathology observed on imaging influences the presence or severity of symptoms is unknown. Comin et al.[11] categorised the Achilles and patellar tendon as containing mild, moderate, or severe hypoechoic areas, moderate/severe pathology increased the risk of symptoms developing in ballet dancers. However, the criteria for categorising the severity of tendon pathology were not described. Conventional US imaging is limited in its ability to quantify intra-tendinous structure, is user-dependent, and relies on subjective interpretation of images. These

* Corresponding author.
E-mail address: s.docking@latrobe.edu.au (S.I. Docking).

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factors may result in false negatives/positives, negatively affecting the predictive power of US imaging. New imaging modalities, such as ultrasound tissue characterisation (UTC), may provide improved prediction and prognosis of symptoms due to its ability to quantify intra-tendinous structure.

The aim of this study was to investigate whether the presence of a pathological Achilles or patellar tendon was related to the presence or development of symptoms in elite male Australian football (AF) players. It was hypothesised that the presence of tendon pathology at baseline (pre-season) would increase the risk of developing symptoms during the season yet will have poor precision (i.e. a high proportion of players with a pathological tendon will not develop symptoms). The second aim was to investigate the relationship between the extent of pathology, quantified by UTC at baseline, and severity of symptoms over the course of a season. It was hypothesised that the extent of disorganisation would not influence the severity of symptoms.

2. Methods

Participants were recruited as part of a larger study investigating the prevalence and morbidity of Achilles and patellar tendinopathy in elite male Australian football players.[12] UTC scans were captured on a sub-cohort of 477 players. An a priori decision was made to prioritise players with current or previous history of Achilles and/or patellar tendinopathy, players with no history of tendon symptoms were recruited where possible. Players with a history of either Achilles and/or patellar tendinopathy underwent bilateral scans of the Achilles and patellar tendons, and those with no history of tendinopathy had a scan of the right Achilles and patellar tendon. Baseline scans were performed in November and December of 2015 during the pre-season training period for the 2016 AFL season. Two repeat scans at 1 month intervals were also captured during the pre-season and at the end of the season, however are not included as part of this study.

Ultrasound tissue characterisation quantifies tendon structure by capturing a 3-dimensional US image of the tendon. UTC has been shown to be reliable in imaging both the Achilles and patellar tendon.[13] A 5–12 MHz linear US probe (SmartProbe 12L5, Terason 2000+; Teratech, Burlington, USA) was mounted in a customised tracking unit (UTC Tracker; UTC Imaging, Stein, the Netherlands), with a built-in standoff pad to maintain adequate contact between the probe and skin. The US parameters were standardised for all scans (12 MHz, focus = 1.3 cm, depth = 3 cm).

Patellar tendon scans were taken with the participant supine with the knee at ~120° knee flexion.[14] Achilles tendon scans were taken with participants in prone with their feet off the edge of the plinth and ankle at 90° dorsiflexion.[13,15] The tracking unit automatically moved the transducer distally capturing 600 transverse grey scale images at an interval of 0.2 mm. From this, a 3-D grey scale US image was rendered (UTC Analyzer v2.0.0; UTC Imaging, Stein, the Netherlands).

Each tendon was classified as pathological or normal using a previously published decision-making algorithm, based on either the presence of a hypoechoic area, or focal/diffuse tendon thickening observed on grey-scale US.[14] Anterior-posterior (AP) diameter was calculated at the thickest point of the tendon in the transverse plane.

Tendon structure was quantified using the previously published and validated UTC algorithm.[13] This algorithm quantifies the stability of the echopattern of contiguous transverse images, with a stable echopattern representing parallel tendon bundles. As echo-type III and IV are generated by interfering echoes they were grouped together and termed disorganised tissue structure (DIS).[13] A window size of 25 was selected for all analyses.

For each tendon, regions of interest (ROI) were placed around the border of the tendon in the transverse view. For the Achilles tendon, ROI's were selected from the disappearance of the calcaneus to the musculotendinous junction at regular intervals no greater than 5 mm apart. A similar method was used for the patellar tendon, where ROI's were discriminated from the disappearance of the inferior patella pole to 3 cm distal. Based on the manually defined ROI's, the UTC software (UTC Analyzer v2.0.0; UTC Imaging, Stein, the Netherlands) interpolated contiguous ROI's to create a tendon volume where the relative percentages of all echo-types were quantified.

All analyses of tendon structure were performed by a single investigator (SID) with 8 years experience in tendon imaging and UTC, blinded to player, limb, and clinical history. The described method has been shown to be reliable, with a reported minimum detectable difference of 0.9% and 1.7% for quantifying the percentage of DIS in the Achilles and patellar tendon, respectively.[14] All analyses were performed independently for the Achilles and patellar tendon. One side was selected for each participant to ensure independence of observations. If bilateral scans were captured, the tendon that exhibited pathology was selected. If bilateral pathological or normal tendons were observed, one tendon was selected by coin flip.

A modified version of the Oslo Sports Trauma Research Centre (OSTRC) overuse injury questionnaire was used to identify the presence of Achilles or patellar tendon symptoms. The OSTRC questionnaire consists of four multiple choice questions, capture the impact of an injury in the last week on the players' ability to participate, train and perform, as well as the severity of any pain.[16] The questionnaire was duplicated to allow investigation of both 'Achilles tendon problems' and 'patellar tendon problems', separately. A score out of 100 was calculated (multiple choice categories and scoring system outlined in Clarsen et al.),[16] with a score of 0 indicating no tendon symptoms, and full participation in training and competition.

Participants completed the first OSTRC questionnaire in the same session as their baseline UTC scan, and completed monthly questionnaires over the course of the 9-month pre- and competitive season via an online questionnaire (GoogleDrive; Google, USA). Participants were excluded if they completed fewer than four of the possible nine surveys. Participants were classified as having either Achilles or patellar tendon symptoms at baseline (OSTRC score > 0), or having *developed* symptoms during the season (OSTRC score = 0 at baseline, but a score of >0 in the subsequent surveys). The OSTRC score at baseline and average OSTRC score for the season (cumulative OSTRC season score divided by number of valid (i.e. completed) responses) were calculated.

Players were also asked 'do you have a previous history of tendon problems' for both the right and left Achilles and patellar tendon at baseline.

Two-by-two contingency tables were generated comparing pathology on grey-scale US in comparison to the presence of symptoms at baseline and the development of symptoms during the season (SPSS version 24; SPSS Inc, Chicago, USA). Similarly, previous history of tendon symptoms was compared to the development of symptoms during the season for the original cohort of 441 participants (Docking et al., in submission). Measures of diagnostic accuracy (sensitivity, specificity, negative predictive values, positive predictive value) were calculated (MedCalc version 17.4). Risk factor analysis was also performed to calculate the odds ratio and relative risk, which was determined to be significant if the 95% confidence interval did not include 1.

Continuous UTC parameters (AP diameter and percentage disorganisation) were analysed by calculating diagnostic accuracy measures and relative risk at each recorded value. Similarly, the relative risk of a pathological tendon developing symptoms was

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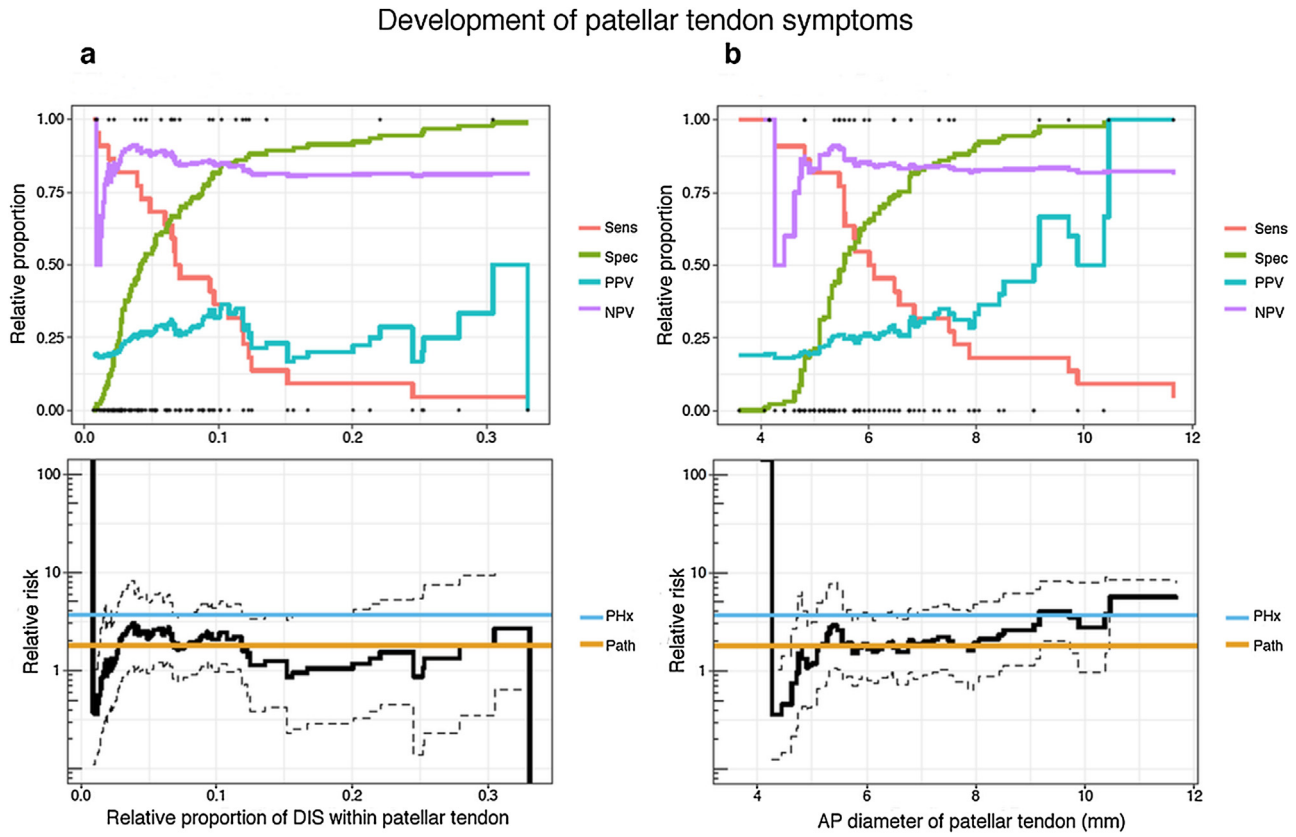

Fig. 1. Prognostic accuracy measures and relative risk for the development symptoms for each recorded value of (a) percentage of DIS structure and (b) AP thickness of the patellar tendon. Solid dots represent the percentage of DIS structure or AP diameter for each individual (n = 130) and the development symptoms (0 = no symptoms, 1 = symptoms). Solid black line represents the relative risk, with dashed lines demonstrating 95% confidence intervals. Solid yellow line represents the relative risk for development of symptoms based on pathology observed on grey-scale US. Solid blue line represents the relative risk for development of symptoms based on previous history of symptoms. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Table 1
Demographics of participants (n = 179).

Variable	Achilles (n = 163)	Patellar (n = 171)
Age (years); mean (SD)	23.9 (3.7)	23.8 (3.7)
Height (cm); mean (SD)	189.5 (8.0)	189.9 (8.1)
Match experience; n (% of total)		
No matches	27 (16.6%)	29 (17.0%)
1–49 matches	69 (42.3%)	72 (42.1%)
50–99 matches	30 (18.4%)	35 (20.5%)
100+ matches	37 (22.7%)	35 (20.5%)
Tendon symptoms		
Symptoms at baseline	26 (16.0%)	41 (24.0%)
Developed symptoms	30 (18.4%)	24 (14.0%)
No symptoms	107 (65.6%)	106 (62.0%)
Previous history of symptoms	44 (27%)	82 (48%)

calculated at each recorded value, based on the continuous season average OSTRC score. This enabled the full spectrum of possible clinical decision rules to be examined, as opposed to reporting the results of a single dichotomous decision rule (e.g. a ROC derived cut-off).

Linear regression was performed to determine whether UTC parameters were related to the OSTRC score, either at baseline or average season score.

3. Results

A total of 179 players from 10 clubs had tendon imaging, with 163 and 171 participants undergoing imaging of their Achilles and patellar tendon respectively (Table 1). Grey-scale features were recorded in all participants, however UTC parameters were unable to be calculated in some participants due to imaging artefact (14 and 19 participants for the Achilles and patellar, respectively).

Patellar tendon pathology on grey-scale US was significantly associated with the development of self-reported symptoms. Participants with a pathological patellar tendon were 13-times (95% CI 4.2–40.9) more likely to have symptoms at baseline (Supplementary material 1). While grey-scale pathology demonstrated excellent sensitivity, results for specificity and PPV were poor-to-fair. This was due to 54.8% of pathological tendons being asymptomatic at baseline.

A percentage of DIS above ~2.5% was a significant risk factor for the presence of symptoms at baseline (Supplementary material 2). Furthermore, a thickened tendon between ~5 and ~9 mm was a significant risk factor for the presence of symptoms (Supplementary material 2). Both of these variables displayed a reduced relative risk compared to pathology observed on grey-scale US.

The strongest associated risk factor for the development of patellar tendon symptoms was a previous history of patellar tendon injury (Supplementary material 1). While pathology on US was a strong associated risk factor for symptoms at baseline, it was not significantly associated for the development of symptoms (i.e. season average OSTRC score > 0) (Supplementary material 1). However, when the relative risk was calculated for each recorded season average OSTRC value in those who developed symptoms, pathology on US was a significant risk factor for the development of symptoms with increasing symptom severity (Supplementary material 3). Tendon AP diameter and percentage of DIS were not significant risk factors for the development of symptoms (Fig. 1).

Both AP diameter ($R^2 = 0.181$, B ± standard error = 4.3 ± 0.7) and percentage of disorganisation ($R^2 = 0.178$, B ± standard

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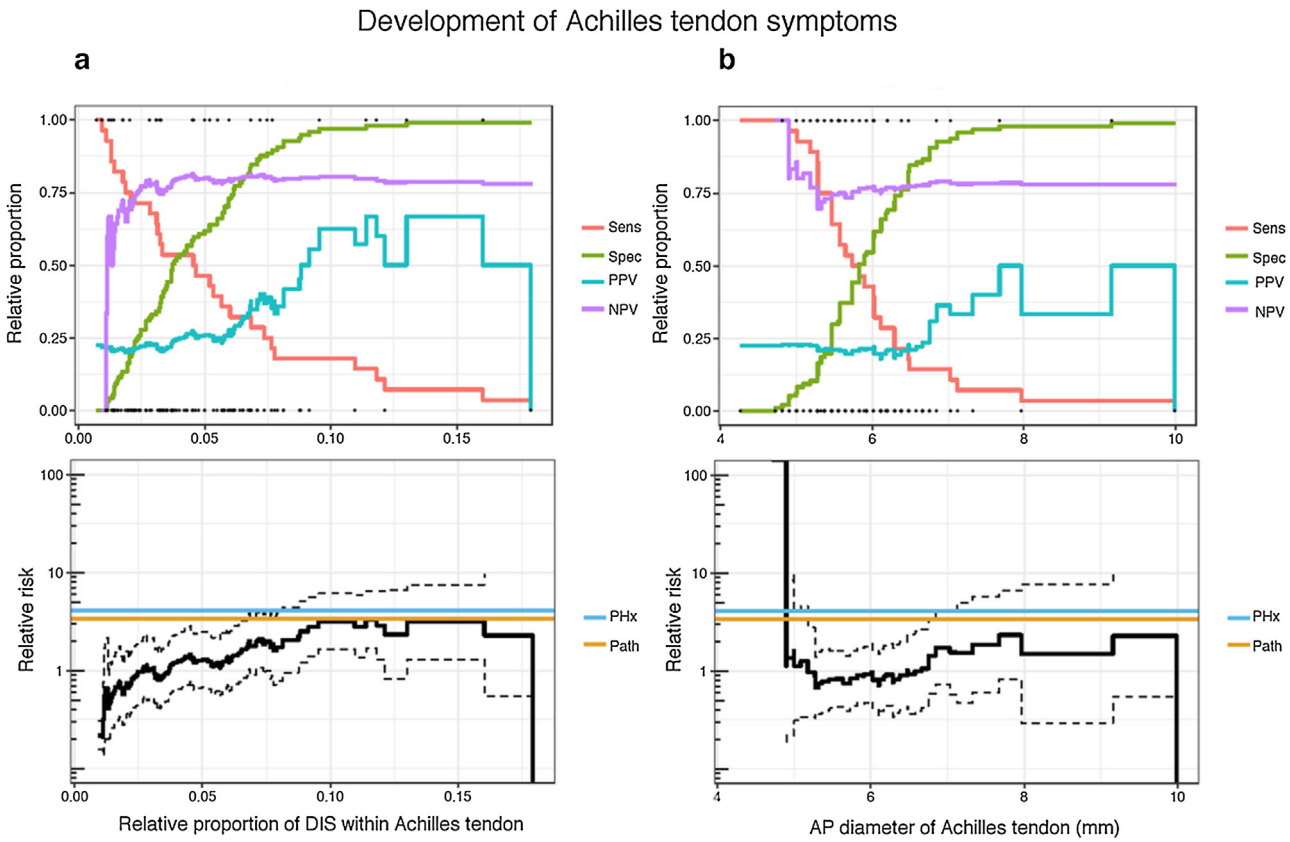

Fig. 2. Prognostic accuracy measures and relative risk for the development symptoms for each recorded value of (a) percentage of DIS structure and (b) AP thickness of the Achilles tendon. Solid dots represent the percentage of DIS structure or AP diameter for each individual (n = 137) and the development symptoms (0 = no symptoms, 1 = symptoms). Solid black line represents the relative risk, with dashed lines demonstrating 95% confidence intervals. Solid yellow line represents the relative risk for development of symptoms based on pathology observed on grey-scale US. Solid blue line represents the relative risk for development of symptoms based on previous history of symptoms. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

error = 88.9 ± 15.6) showed a weak relationship with severity of symptoms at baseline. The relationship between UTC parameters and average OSTRC score for the season were stronger, with AP diameter explaining ~31% of the variance (R^2 = 0.318, B ± standard error = 3.9 ± 0.4) and percentage of disorganisation explaining ~26% of the variance (R^2 = 0.266, B ± standard error = 73.6 ± 10.0).

Participants with a pathological Achilles on grey-scale US were ~8-times (95% CI 4.3–16.5) more likely to be symptomatic at baseline (Supplementary material 4). Grey-scale US demonstrated an excellent ability to rule out the presence of symptoms at baseline (i.e. specificity and NPV) and a moderate ability to identify symptomatic participants (i.e. sensitivity and PPV). Percentage of DIS and AP diameter were significant risk factors above 6% and 6 mm, respectively (Supplementary material 5). Relative risk of symptoms at baseline for these variables were similar or lower than that reported for pathology on grey-scale US.

Both pathology on grey-scale US and a previous history of symptoms were equally strong associated risk factors for the development of symptoms (Supplementary material 4). While these were risk factors, both were limited in identifying participants who will develop symptoms (i.e. sensitivity). When the relative risk was calculated for each recorded season average OSTRC value in those who developed symptoms, the relative risk of pathology on US increased with increasing severity of symptoms (i.e. participants with a pathological tendon were ~12-times more likely to develop symptoms greater than a season average OSTRC score of 8) (Supplementary material 6). AP diameter and percentage of DIS were not predictive for the development of symptoms (Fig. 2).

Percentage of disorganisation (R^2 = 0.102, B ± standard error = 77.7 ± 19.0) and AP diameter (R^2 = 0.172, B ± standard error = 4.1 ± 0.7) showed an unimportant-to-weak relationship with severity of symptoms at baseline. The strength of the relationship for AP diameter (R^2 = 0.176, B ± standard error = 2.2 ± 0.4) and percentage of DIS (R^2 = 0.070, B ± standard error = 38.5 ± 11.6) in relation to average OSTRC score for the season was similarly unimportant-to-weak.

4. Discussion

This study provides further evidence that baseline imaging can identify athletes who are at-risk of having, or developing, symptoms of Achilles or patellar tendinopathy. Participants with asymptomatic pathological Achilles tendon at baseline were ~3-times more likely to develop symptoms, yet having a pathological patellar tendon at baseline did not significantly increase the risk of developing symptoms. The novel finding from this study is that continuous variables of tendon integrity, AP diameter and percentage of DIS on UTC, may not improve the ability of imaging to predict baseline or future symptoms.

A multitude of risk factors have been identified for the development of Achilles and patellar tendon symptoms, such as increased body mass index,[17,18] both reduced[19] and increased ankle dorsiflexion range[20]; and increased training and competition volume in volleyball players.[21] Where odds ratio and relative risk have been quantified, tendon pathology observed on imaging has consistently been shown to be the strongest predictor of symptoms. McAuliffe et al.'s[10] systematic review reported a greater relative risk for Achilles tendon pathology than the current study. Furthermore, pathology within the patellar tendon was a significant risk factor in the meta-analysis,[10] but this was not observed in the cur-

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rent study. In comparison to previous studies, results from this population of elite AF players showed a larger proportion of tendons that were normal at baseline developing symptoms. One of the potential reasons for this difference is due to the difference in how injuries/symptoms were classified.

The criteria used for classifying injured and non-injured participants vary between studies. The most common method is a combination of interview and clinical assessment at the end of the study period,[9,22,23] however this method is limited as it relies on recall and may miss subtle transient symptoms. Other studies have prospectively followed athletes and measured an injury if the player missed training or competition.[11,24] The strength of the method was that it did not emphasise a time-loss definition that likely underestimates tendon injury in this elite athlete cohort.[12] The method also avoided problems associated with participant recall of signs/symptoms, which can be inaccurate over a long period. However, reliance on self-reported signs/symptoms, reported in terms of impact on performance, participation, function and pain introduces other challenges. In particular, there is the potential that participants may have reported symptoms that were not tendon-related, but rather another localised pathology (e.g. patellofemoral pain rather than a patella tendinopathy). This has the potential to effect measures of diagnostic accuracy.

An inclusive definition of Achilles/patellar problems impacting on performance, participation, function and pain, instead of a time loss definition, was used. The questionnaire was based on self-reported symptoms only, and there is the potential that participants may have reported tendon symptoms where it may be another condition (i.e. patellofemoral pain for anterior knee pain). The use of this injury definition has the potential to effect measures of diagnostic accuracy. As this study included 477 participants from 12 clubs in four states, it was not feasible for an investigator to be at the club every month to undertake a clinical examination. Due to ethical considerations, the clubs medical team were blinded to results from the OSTRC questionnaire, hence they were unable to undertake a standardised clinical examination to reinforce findings from the OSTRC questionnaire. Furthermore, it is unclear how diagnostic tests such as palpation differentiate between conditions at the knee.[25] For future studies, the inclusion of additional questions may aid in improving the accuracy of this self-reported outcome measure, such as a pain map during a pain provocation test.

The use of the OSTRC questionnaire as the sole diagnostic criteria for Achilles and patellar tendinopathy is a limitation of this study. Clarsen et al.[16] originally developed the OSTRC questionnaire for determining the impact of overuse injuries based on body site (i.e. knee, lower back, shoulder). Anatomical body sites were the focus as it was expected athletes would not be able to reliably report a more specific structure or tissue without an accurate clinical diagnosis. Since the completion of our study, a new publication has presented a modified OSTRC for patellar tendinopathy (OSTRC-P), wherein specific questions on pain location were asked in combination with the OSTRC questionnaire. The OSTRC-P was shown to have excellent sensitivity and specificity in identifying clinically diagnosed patellar tendinopathy.[26] Similarly, a sub-cohort from the population in our study also completed pain mapping during a provocative task (single-leg decline squat). Participants were able to reliably identify the site and spread of pain, which has been suggested to be useful in diagnosis of tendinopathy.[27,28] While these new findings for diagnostic accuracy in patellar tendinopathy are promising for studies requiring self-reported data, due to the lack of clinical assessment or additional questions (OSTRC-P) in our current study, a degree of caution needs to be applied when interpreting the findings.

While US has demonstrated utility in identifying the at-risk group, it has limited accuracy identifying the individual who will have, or develop, symptoms. This finding questions the clinical practicality of US as a screening tool for injury prevention. An example of this can be demonstrated based on the current data, where a theoretical injury prevention program is directed only to those players with a pathological tendon on US. In this case, 50–80% of players who did not receive the program (because their tendons were normal at baseline) would go on to develop symptoms during the season. Compared with imaging, the simple question on previous history of symptoms was a stronger risk factor associated with the development of the symptom but did not demonstrate improved sensitivity for identifying symptom development. The saving on cost and time from questioning compared with imaging, without any loss of prognostic accuracy, is noteworthy.

This is the first study to investigate whether quantifying intratendinous tendon structure was prognostic for symptoms during the season. Quantification of tendon structure did not improve diagnostic or prognostic accuracy beyond a dichotomous classification on grey-scale US (i.e. normal or pathological). Furthermore, there was a poor linear relationship between the extent of disorganisation and the severity of symptoms, either current or future. Previous studies have found no relationship between baseline imaging parameters (MRI signal intensity, CSA, and presence of Doppler signal) and improvement in symptoms following treatment,[29,30] suggesting that the extent of disorganisation is not a factor limiting resolution of symptoms.

This prospective study included data on 179 elite AF players, across 10 clubs, nationally. However, there was selection bias because it was not possible to scan all 477 professional players included in the larger study due to time constraints. A decision was made to target those with a current or history of tendon symptoms and capture a random sample of participants with no history of tendon symptoms, potentially leading to an over-estimation of the relative risk. If you assume all players not scanned have a normal tendon, the relative risk is unchanged or increases due to the increase of normal tendons remaining asymptomatic.

5. Conclusion

Similar to previous studies, intra-tendinous pathology on grey-scale US was a risk factor of the presence and development of tendon symptoms. This was the first study to show that continuous measures of tendon integrity were not associated with an increased risk for the development of symptoms. However, this study was limited to a single scan at the start of the season. Future studies are needed to ascertain whether the development or progression of tendon disorganisation is associated with the development of symptoms.

Practical implications

- Baseline ultrasound imaging is associated with an increased risk of having or developing symptoms. However, imaging is poor at identifying the individual's risk due to a high proportion of asymptomatic pathological tendons.
- Previous history of symptoms was a stronger risk factor for the development of symptoms, and demonstrated greater diagnostic and prognostic accuracy.
- Measuring the severity of pathology using UTC at baseline does not explain the presence of severity of symptoms at baseline, or in the future.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at https://doi.org/10.1016/j.jsams.2018.07.016.

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