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Does the adolescent patellar tendon respond to 5 days of cumulative load during a volleyball tournament?

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Patellar tendinopathy (jumper's knee) has a high prevalence in jumping athletes. Excessive load on the patellar tendon through high volumes of training and competition is an important risk factor. Structural changes in the tendon are related to a higher risk of developing patellar tendinopathy. The critical tendon load that affects tendon structure is unknown. The aim of this study was to investigate patellar tendon structure on each day of a 5-day volleyball tournament in an adolescent population (16–18 years). The right patellar tendon of 41 players in the Australian Volleyball Schools Cup was scanned with ultrasound tissue characterization (UTC) on every day of the tournament (Monday to Friday). UTC can quantify structure of a tendon into four echo types based on the stability of the echo pattern. Generalized estimating equations (GEE) were used to test for change of echo type I and II over the tournament days. Participants played between eight and nine matches during the tournament. GEE analysis showed no significant change of echo type percentages of echo type I (Wald chi-square = 4.603, d.f. = 4, $P = 0.331$) and echo type II (Wald chi-square = 6.070, d.f. = 4, $P = 0.194$) over time. This study shows that patellar tendon structure of 16–18-year-old volleyball players is not affected during 5 days of cumulative loading during a volleyball tournament.

Patellar tendinopathy, also known as jumper's knee, is an overuse injury of the patellar tendon that causes load-related focal pain usually at the tendon insertion to the patella. Patellar tendinopathy causes pain and dysfunction predominantly in jumping athletes (Ferretti et al., 1984; Zwerver et al., 2011), which may result in cessation of sport (Kettunen et al., 2002). The prevalence in elite volleyball athletes is as high as 45% (Lian et al., 2005), while a prevalence of 14.4% has been reported in recreational volleyball players (Zwerver et al., 2011).

Patellar tendinopathy is diagnosed clinically, and confirmed with ultrasound imaging or magnetic resonance imaging. Although the presence of ultrasound abnormalities in a tendon is not directly correlated with pain (Khan et al., 1996; Lian et al., 1996), current literature suggests that athletes with structural changes in their tendon have a higher risk of developing patellar tendinopathy than athletes without structural changes (Cook et al., 2000b; Fredberg & Bolvig, 2002; Gisslen & Alfredson, 2005; Gisslen et al., 2007; Fredberg et al., 2008; Comin et al., 2013; Giombini et al., 2013; Visnes et al., 2014).

Tendon structure has been difficult to measure until recently, where higher level analysis of ultrasound images has allowed quantification of tendon structure. Kulig et al. (2013) used fast Fourier transformation of ultrasound images and showed that tendon structure on ultrasound (peak spatial frequency) could discriminate between athletes with and without patellar tendinopathy. Similarly, van Schie et al. (2003) developed an algorithmic enhanced ultrasound analysis [ultrasound tissue characterization (UTC)] that can quantify the structure of a tendon based on the stability of the echo pattern by calculating percentages of four echo types (echo type I being the most stable and echo type IV being the least stable echo type). UTC has been found to have good inter-tester reliability [intraclass correlation coefficient (ICC) > 0.9] in quantifying tendon structure (van Schie et al., 2010). It has also been shown that UTC can discriminate between symptomatic and asymptomatic Achilles tendons (van Schie et al., 2003); other validity data in humans are not yet available.

Many intrinsic and extrinsic factors may contribute to patellar tendinopathy and structural change. Extrinsic factors, especially excessive load through a high volume of training and competition, seem to be the most important risk factors (Visnes & Bahr, 2013). The amount of mechanical load placed on the tendon in sporting activities includes the intensity, volume, and frequency of patellar tendon loading; in this paper, this will be called tendon load. It is unknown how much tendon load it takes to result in patellar tendinopathy and structural change. Insufficient rest of the tendon after an acute bout of load might result in cumulative structural changes (Magnusson et al., 2010). The acute response of a tendon to load in a competitive sport setting has only recently been investigated in the Achilles tendon; structural changes were reported 2 days after an Australian football match (Rosengarten et al., 2015).

Intrinsic factors to be considered include age, body composition, and genetics (van der Worp et al., 2011; Salles et al., 2015). Of these factors, age seems to be an important factor. The relationship between structural changes and development of patellar tendinopathy symptoms seems more closely related in younger athletes than adults (Visnes et al., 2014). Additionally, several studies show a high prevalence of patellar tendinopathy in teenage athletes, which might indicate that young athletes are prone to develop patellar tendinopathy (Cook et al., 2000a; Gisslen et al., 2007; Cassel et al., 2014). Another intrinsic risk factor to be considered is sex; a different prevalence has been reported between male and female athletes (Lian et al., 2005; Zwerver et al., 2011).

The response of the patellar tendon to tendon load, how tendons react to a bout of cumulative high load, and if adolescents are susceptible to acute load-induced structural changes is unknown. To our knowledge, no previous studies investigated the response of a tendon during cumulative high bouts of loading during several days. The aim of this study was to investigate the response of the patellar tendon on UTC imaging during a 5-day volleyball tournament in an adolescent population (16–18 years old). Secondary aims of the study were to examine if patellar tendons of participants with hypoechoic abnormalities respond differently to tendon load than players without hypoechoic abnormalities and if the response to load varies by sex. A change in tendon structure during the tournament expressed by a decrease in echo type I and a coinciding increase in echo type II were hypothesized.

Materials and methods

Victorian teams playing in the top division in the Australian Volleyball Schools Cup (AVSC) were approached to participate in the study. AVSC is a competitive 5-day schools volleyball tournament. Six teams agreed to allow recruitment of players in their team. All participants provided informed consent and players aged 16 years or more were able to provide consent without parental approval. The study was approved by the Monash University Human Research Ethics Committee, Australia (CF13/2202 – 2013001164).

Standard anthropometric measures (height, weight, waist circumference) and a UTC scan were obtained at baseline (week before the tournament). Participants were asked if they had any knee pain and when answered "yes," their knee was assessed by a physiotherapist to establish if the participant had patellar tendon pain or another knee injury. The clinical assessment was done by taking a history and testing the pain location on a single leg decline squat (Purdam et al., 2003; Zwerver et al., 2007). Hypoechoic abnormalities in the patellar tendon were also recorded. Hypoechoic abnormality was defined as a hypoechoic zone visible on gray-scale ultrasound image of the tendon in the transverse and sagittal plane.

A UTC scan of the patellar tendon was performed on every day of the tournament. Furthermore, participants were asked about their knee pain on each day. When participants indicated that they had pain on a particular day, the single leg decline squat was used as a patellar tendon pain provocation test. Participants were asked to estimate the percentage of points that they were playing (not substituted) and the number of sets and points played by their team was recorded. On the final day, the question "What was last week like compared to physical activity loading your knee in the last three months?" was asked to measure the subjective load on the knee. Participants were asked to answer this question on a 9-point global rating of change scale ranging from –4 (very much less activity) to +4 (very much more activity).

The UTC scan was obtained during the tournament days at one of three playing venues. A UTC machine has an ultrasound probe (SmartProbe 12L5-V, Terason 2000+; Teratech, Burlington, Maryland, USA) fixed in a tracking device (UTC Tracker, UTC Imaging, Stein, The Netherlands) to ensure a consistent transducer tilt angle in relation to the tendon. The tracker device moves the ultrasound probe automatically with a consistent speed perpendicular along the tendon long axis. An ultrasound image of the transverse plane of the tendon is captured every 0.2 mm over the length of the patellar tendon. The UTC software (UTC 2011, UTC Imaging) constructs the sagittal and coronal planes from the transverse images creating a 3D ultrasound data block (van Schie et al., 2010). The right knees of participants were scanned based on previous studies that showed that a majority of patellar tendinopathies in volleyball players occur in the right patellar tendon (Lian et al., 2003; Malliaras et al., 2006; Bisseling et al., 2008; Helland et al., 2013). Participants were scanned by one of two trained researchers (M. v. A., S. D.). Participants lay supine on a treatment bench; their knee was bent to an approximate 100° of knee flexion in which a clear image could be obtained with the ultrasound probe in the tracker perpendicular to the long axis of the tendon. A picture of the UTC scan set up is shown in Fig. 1.

The consistency of intensity and distribution of gray levels of images over a length of 4.8 mm (25 images) was quantified by using computer algorithms. Based on the consistency, four echo types were created for every transverse image. The four echo types range from the most stable echo pattern (echo type I) to the least stable echo pattern (echo type IV; van Schie et al., 2003, 2010). The tendon was analyzed from the apex of the patella to 20 mm distally; percentages of these echo types in this region of interest (RoI) were calculated. This RoI was chosen because pain and change of structure are normally localized in this area. To quantify echo types in this area, tendon contours were marked by a trained researcher (M. v. A.). All scans were de-identified before marking the contours to ensure the researcher was blind to participant and day of the scan. All scan contours were reviewed by both trained researchers to ensure consistency and poor quality scans were excluded. If consensus was not reached a third assessor made a final decision (6% of the scans).

This study examined echo types I and II because short-term changes in these echo types have been shown in previous studies (Rosengarten et al., 2015). Inter- and intra-observer reliability was assessed in 18 tendons.

Statistical analysis

Data were analyzed for normality, distribution of echo types I and II were found to be normal (Q-Q plots were assessed and Shapiro–Wilk tests were not significant). To establish if tendon structure was not fluctuating in the days before the tournament, a paired *t*-test was run. Echo type percentages from baseline and day 1 (Monday) measurements were compared.

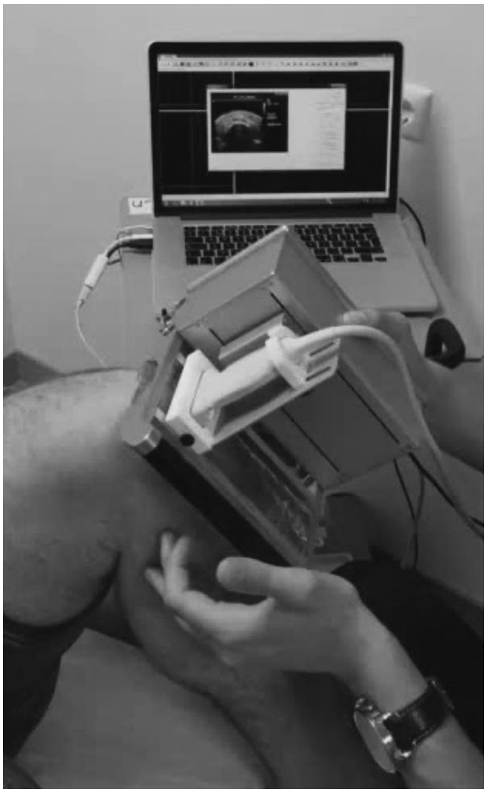

Fig. 1. Setup of ultrasound tissue characterization scan of the patellar tendon.

Generalized estimating equations were used to test for change of echo type I and II over the tournament days. Separate models were run for echo type I and echo type II, with echo type as dependent variable. Participant (ID number) was used as subject variable. Main effect of time (days of the tournament) was determined. An exchangeable working correlation matrix was used.

To test for the secondary aims of the study, two models were run. In a second model, hypoechoic abnormality was added to the first model; the main effect of hypoechoic abnormality and interaction effect time by hypoechoic abnormality was determined. A third model was run adding sex to the first model; its main effect together with the interaction effect time by sex was determined.

Results

Forty-one players from six different teams were recruited (Table 1). Two participants were excluded from all data analyses because of poor quality scans due to anisotropy or imaging artifacts; each day, some scans were not analyzed because of their quality (Table 2). No significant changes were found between echo types on baseline and the first day of the tournament [echo type I: $t(27) = 1.441$, $P = 0.161$; echo type II: $t(27) = -1.083$, $P = 0.288$].

Every team played eight or nine matches during the tournament, with a mean (SD) of 28.0(2.8) sets. The mean estimated number of points played (not substituted) by an individual athlete was 871 ± 308 points. The subjective load on the knee during the tournament week compared with normal physical activity in the last 3 months was +1.8 ± 1.6 on a 9-point global rating of change scale, indicating an increase in knee load. Four participants indicated that the tournament week was less physical activity loading their knee.

Table 1. Baseline participant demographics and tendon characteristics

Measure	Mean (SD)
Sex (M:W)	30:11
Age (years)	17.2 (0.8)
Height (cm)	180.8 (7.3)
Weight (kg)	73.6 (11.2)
Number of times volleyball normal week	2.7 (1.5)
Hypoechoic abnormality (yes:no)	14:25
Patellar tendon pain before tournament (yes:no)	8:33
Patellar tendon pain at least 1 day of tournament (yes:no)	15:26
Echo type I (%) $n = 30$	58.7 (11.4)
Echo type II (%) $n = 30$	39.4 (9.8)
Echo type III (%) $n = 30$	1.6 (2.8)
Echo type IV (%) $n = 30$	0.3 (0.5)

SD, standard deviation.

Eight participants reported patellar tendon pain at baseline; an additional seven reported patellar tendon pain on one or more days during the tournament. Fourteen of the 39 analyzed tendons showed hypoechoic abnormalities. Eleven of those 14 also reported pain on at least 1 day of the tournament. Four participants reported patellar tendon pain but did not show hypoechoic abnormalities. Twenty-one participants did not have patellar tendon pain or hypoechoic abnormalities.

The echo type percentages were calculated for each day of the tournament (Table 3). There was no

Table 2. Number of scans completed each day of the tournament

	Scans completed	Scans included	Scans excluded (low quality)*
Baseline	41/41	30/41	11/41
Monday	41/41	37/41	4/41
Tuesday	41/41	37/41	4/41
Wednesday	39/41	36/39	3/39
Thursday	40/41	32/40	8/40
Friday	38/41	32/38	6/38
Total	240/246	204/240	36/240

*It was not possible to obtain a good scan on every day for two participants.

significant change in echo types over the 5 days of the study [echo type I: Wald chi-square = 4.603, d.f. = 4, $P = 0.331$; echo type II: Wald chi-square = 6.070, d.f. = 4, $P = 0.194$ (Fig. 2)].

When hypoechoic abnormality was added to the model, a significant difference in echo type I percentages in those with and without a hypoechoic abnormality was found (Wald chi-square = 16.545, d.f. = 1, $P < 0.001$); however, this was not the case for echo type II (Wald chi-square = 2.864, d.f. = 1, $P = 0.091$). The way echo type I (Wald chi-square = 3.853, d.f. = 4, $P = 0.426$, Fig. 3) and echo type II (Wald chi-square = 4.205, d.f. = 4, $P = 0.379$) changed over time was not significantly different between participants with and without hypoechoic abnormalities.

There were no significant differences between men and women for echo type I (Wald chi-square = 1.818, d.f. = 1, $P = 0.178$) and echo type II (Wald chi-square = 3.401, d.f. = 1, $P = 0.065$). No difference between men and women in the way echo type I percentages changed over time was found (Wald chi-square = 3.457, d.f. = 4, $P = 0.484$); however, the way echo type II percentages changed over time was significantly different for men and women (Wald chi-square = 12.270, d.f. = 4, $P = 0.015$). They showed a similar minor increase over 5 days but day-to-day differences between men and women.

Reliability tested in 18 tendons showed an ICC for intra-observer reliability of 0.82 (0.66–0.91) for echo type I and 0.82 (0.65–0.91) for echo type II with a mean difference of 0.6% and a SD of 5.8 for echo type I and the same mean difference with a SD of 5.9 for echo type II. The ICC for Inter observer reliability was 0.73 (0.49–0.91) with a mean difference of 2.2% for echo type I and 0.73 (0.49–0.87) with a mean difference of 2.1% for echo type II and a SD of 7.1 for both echo types.

Discussion

This study investigated the effect on tendon structure of cumulative loading of the patellar tendon in a competitive high loading volleyball environment. This study showed no change in the echo pattern of the

Table 3. Mean (SD) percentage of echo types I and II during tournament days

	Total population		No hypoechoic abnormality		Hypoechoic abnormality		Men		Women	
	% Echo type I	% Echo type II	% Echo type I	% Echo type II	% Echo type I	% Echo type II	% Echo type I	% Echo type II	% Echo type I	% Echo type II
Monday	54.5 (10.3) *n* = 37	43.2 (8.9) *n* = 37	57.3 (9.0) *n* = 24	42.3 (8.8) *n* = 24	49.4 (11.1) *n* = 13	44.9 (9.1) *n* = 13	55.8 (10.2) *n* = 28	42.2 (9.3) *n* = 28	50.7 (10.3) *n* = 9	46.2 (7.0) *n* = 9
Tuesday	53.3 (8.9) *n* = 37	44.2 (8.2) *n* = 37	55.6 (8.1) *n* = 23	44.0 (7.8) *n* = 23	49.6 (9.2) *n* = 14	44.5 (9.2) *n* = 14	54.0 (9.4) *n* = 28	43.9 (9.1) *n* = 28	51.2 (7.2) *n* = 9	45.0 (5.4) *n* = 9
Wednesday	54.3 (9.1) *n* = 36	43.1 (8.0) *n* = 36	57.8 (8.0) *n* = 23	41.6 (7.7) *n* = 23	48.0 (7.7) *n* = 13	45.7 (8.2) *n* = 13	55.6 (9.5) *n* = 28	41.5 (8.0) *n* = 28	49.5 (5.4) *n* = 8	48.7 (5.5) *n* = 8
Thursday	51.7 (11.4) *n* = 32	45.6 (9.5) *n* = 32	55.3 (11.0) *n* = 21	44.3 (10.7) *n* = 21	44.9 (9.2) *n* = 11	48.2 (6.3) *n* = 11	52.7 (10.8) *n* = 25	44.8 (9.6) *n* = 25	48.3 (14.0) *n* = 7	48.5 (9.0) *n* = 7
Friday	52.4 (12.3) *n* = 32	45.1 (10.2) *n* = 32	57.9 (7.9) *n* = 20	41.8 (7.7) *n* = 20	43.3 (13.3) *n* = 12	50.5 (11.8) *n* = 12	53.0 (12.9) *n* = 24	44.3 (10.4) *n* = 24	50.7 (11.0) *n* = 8	47.4 (9.7) *n* = 8

SD, standard deviation.

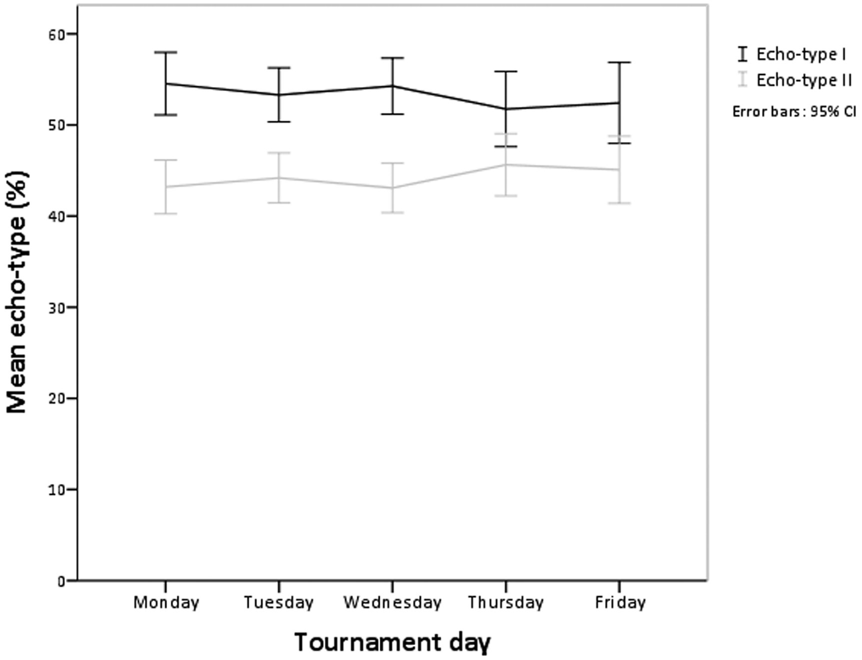

Fig. 2. Mean echo type I and II percentages during tournament days.

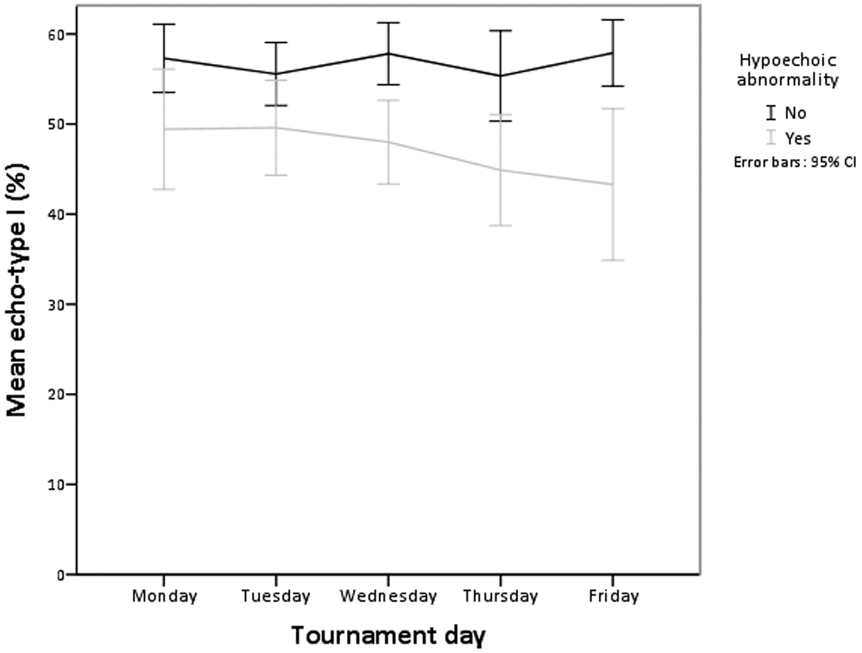

Fig. 3. Mean echo type I during tournament days for athletes with and without hypoechoic abnormalities at the start of the tournament.

patellar tendon of adolescent volleyball players over several days of cumulative loading during a volleyball tournament.

Based on previous studies, we hypothesized change in tendon structure during the tournament expressed by a decrease in echo type I and a coinciding increase in echo type II. Achilles tendon structure on UTC after an Australian football match showed a decrease in echo type I and an increase in echo type II after 2 days and a return to baseline values 4 days after the match (Rosengarten et al., 2015). A similar change in echo types on UTC imaging was found in superficial digital flexor tendons of thoroughbred racehorses after loading (Docking et al., 2012). On the contrary, in recreational runners, a difference in Achilles tendon structure on UTC imaging 2 and 4 days after a 10-km run was not found (Wong et al., 2014). The differences in findings between the studies can partly be explained by the difference in characteristics of the population. For example, Rosengarten et al. (2015) investigated participants without Achilles tendon pain; other studies had subjects with tendon pain and abnormality in their study. Another reason for different findings might be that this is the first UTC study on the patellar tendon; all other studies in humans have been performed on the Achilles tendon. It is likely that a different echo type distribution exists between tendons; more research is needed to confirm this. Furthermore, the number of studies using UTC is still small. Values for percentages of echo types I and II also differ per study performed with UTC. This study showed a higher percentage echo type II than any of the other studies using UTC (van Schie et al., 2010; de Vos et al., 2011, 2012; Rosengarten et al., 2015). Rosengarten et al. (2015) showed a much higher percentage of echo type I (92%) compared with this study, other studies showed lower percentages of echo type I (34–49%). It is not possible to draw conclusion from these differences because UTC echo type percentages are not comparable between studies unless exactly the same settings and UTC model have been used.

The results of the analyses with window size 25 were used in this study because this window size was also used in previous studies using UTC. Post-hoc analyses were also performed with window sizes 17 and 9. Change in echo type percentages over time was not statistically different when analysis was performed using different window sizes (results not shown).

Many practical issues are involved in conducting a cohort study such as this where the environment is hard to control. However, the advantage of investigating the response of a real-life tendon load outweighs the disadvantage of not being able to control all aspects. Access to players was sometimes hampered by coaches who wanted to instruct their players, who in turn were distracted by the tournament environment and the varying duration and venues of games. Finding a suitable time for a UTC scan of participants was one of the logistical challenges. Most scans were performed after the first match of the day. Although previous studies have shown an immediate decrease in anterior-posterior tendon diameter immediately post-exercise (Wearing et al., 2014), mechanical loading seems to take some time to exert effect on the structure of the tendon detected by UTC. A review on the response of a tendon to loading proposed that the metabolic response peaks only 24 h after mechanical loading (Magnusson et al., 2010) In addition, no changes in echo types were found 1 day after an Australian football game, while there was a change in structure 2 days after a game (Rosengarten et al., 2015). As tendon structure is not immediately affected by exercise as tendon dimensions are, a variable time of day (of the UTC scans) will probably not have influenced the outcome for this study.

One of the most important variables to influence tendon structure is the load on the patellar tendon (Visnes & Bahr, 2013). Objective and subjective data showed that the tournament was a heavy load. We objectified the tendon load by calculating the total number of games, sets, and points played including an individual estimation of total number of points played every day. This showed that on average, 871 ± 308 points were actually played by an individual during the 5 days of the tournament over eight or nine matches. This was much more than the participants' average number of times playing volleyball in a normal week (2.7 ± 1.5), often including only one match. To see if the participants also subjectively reported a high load a question was asked about their perceived knee loading during the tournament compared with a normal week. The results showed that most participants also perceived the tournament as a high load for their knees. Tendon load will have differed between participants of the study because the number of jumps varies between players (Bahr & Bahr, 2014); however, the data showed that overall the tournament was a high load for the participants.

Preexisting hypoechoic abnormalities on ultrasound might cause a different response of the patellar tendon to tendon load. Secondary analyses showed a significant difference in echo type I percentage between athletes with and without hypoechoic abnormality. This confirms the relation between UTC and gray-scale images. It also seems to be in line with van Schie et al. (2010), when taking into consideration that 11 of the 14 athletes also experienced patellar tendon pain. van Schie et al. (2010) found that UTC discriminated between symptomatic and asymptomatic Achilles tendons. The difference between athletes with and without hypoechoic abnormalities was not significant for echo type II, the difference in findings between echo types I and II might be explained by the fact that symptomatic tendons show higher values of echo type III and IV than controls (van Schie et al., 2010). A lower percentage of echo type I is not necessarily related to an increase in echo type II. Although the effect of preexisting hypoechoic abnormalities over time was not significant, it is worth noticing that a tendency was seen for athletes with hypoechoic abnormalities to have a different response to tendon load than athletes without hypoechoic abnormalities. Cumulative tendon load seems to decrease the stability of echo patterns in athletes with existing hypoechoic abnormalities while athletes without abnormalities do not seem to change in overall echo pattern. This seems to confirm previous findings that the presence of ultrasound changes increases the risk of developing patellar tendinopathy symptoms (Cook et al., 2000b; Fredberg & Bolvig, 2002; Gisslen & Alfredson, 2005; Gisslen et al., 2007; Fredberg et al., 2008; Comin et al., 2013; Giombini et al., 2013; Visnes et al., 2014). When comparing participants with and without tendon pain at least 1 day of the tournament post-hoc, the same trend was observed. This is not surprising because 79% of the participants with hypoechoic abnormalities also reported tendon pain.

A significantly different change of echo type II over time was found between men and women. When looking at the descriptive statistics, men and women seem to show the same trend for echo type II percentages over time. Small day-to-day differences in echo type II between male and female participants might have caused this significant finding by chance.

Limitations

A small number of scans were not good enough to analyze. Any ultrasound scan can vary in quality because of movement artifact, poor contact, hair, sweat, and skin contour. A UTC scan of insufficient quality will have an overrepresentation of echo types II, III, and IV because artifacts and not the structure of the tendon will cause inconsistencies. Therefore, poor quality scans (15%) were excluded from the analysis.

Furthermore, although previous studies on the Achilles tendon (van Schie et al., 2010) and current data on the patellar tendon show good reliability, we recommend further research on the reliability of the UTC in the patellar tendon on a larger population.

Perspectives

This is the first study to investigate the effect of cumulative loading over several days in the patellar tendon in a real-life setting. Similar research has been completed in the Achilles tendon (Rosengarten et al., 2015). The current study shows that 5 days of cumulative loading during a schools volleyball tournament is not detrimental for the structure of the tendon of 16–18-year-old athletes. However, subgroups that show a decrease in structure of the echo pattern after cumulative loading might exist, for example, athletes with preexisting hypoechoic abnormalities. An implication for volleyball organizations is that 5 days of consecutive loading is not detrimental to patellar tendon structure. Further research in this area should focus on different tendon loads and subgroups to find out what the critical load for tendon structure change is. This study should, for example, be replicated in elite athletes and a population with patellar tendinopathy to see if this shows different results.

Key words: Patella, tendinosis, grayscale, hypoechoic, pain, sports medicine.

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Conflicts of interest

Jill Cook is a director and shareholder in Trackside Technologies, the applicant of a patent directed to using ultrasound to monitor connective tissue and compositions for treating connective tissue.

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