The effect of load on Achilles tendon structure in novice runners

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A R T I C L E   I N F O

Article history:
Received 21 September 2016
Received in revised form 27 September 2017
Accepted 6 November 2017
Available online 16 November 2017

Keywords:
Tendinopathy
Achilles tendinopathy
Athletic injuries
Sports medicine
Ultrasonography
Ultrasonographic tissue characterisation

A B S T R A C T

Objectives: To observe the changes in Achilles tendon structure in novice runners, with loading prescriptions of 100% body weight compared to 20% body weight.

Design: Randomised crossover.

Methods: Twenty novice runners participated in two separate running bouts spaced 14 days apart, one of high load at 100% body weight, and one of low load at 20% body weight. Tendon structure was measured by ultrasonographic tissue characterisation on 6 occasions; immediately prior to each run, 2 and 7 days after each run.

Results: The interaction effect of time and condition was not found to be significant for echotypes I–IV [Wald chi-square = 2.8, d.f. = 2, P = 0.247; Wald chi-square = 2.888, d.f. = 2, P = 0.236; Wald chi-square = 1.385, d.f. = 2, P = 0.5; Wald chi-square = 4.19, d.f. = 2, P = 0.123], respectively. A significant effect of time was found for echotypes III [Wald chi-square = 6.785, d.f. = 2, P = 0.0034] and IV [Wald chi-square = 7.491, d.f. = 2, P = 0.0024].

Conclusions: The decrease in echotypes III and IV suggest that moderate loads can be applied to the Achilles tendon without compromising tendon structure. Low to moderate loads may be beneficial in the management of Achilles tendinopathy. Further studies should focus on protocols with higher loading and/or repetitive loading in athletic populations with and without Achilles tendinopathy to assess any differences in tendon structure.

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1. Introduction

Tendinopathy is a frequent overuse complaint that has been estimated to account for 30–50% of all sports related injuries. A recent systematic review on running related musculoskeletal injuries found that Achilles tendinopathy presented as the second highest injury incidence at 9.1–10.9%. The repetitive loading of a tendon during physical activity without adequate time for tendon recovery is assumed to be a major factor influencing the development of a tendinopathy. There has been a model proposed in the literature that describes the continuum of tendon pathology and its relation to load. Based on this model it is proposed that a normal healthy tendon with optimal levels of loading will adapt and strengthen. On the other hand, a healthy tendon that is loaded excessively and without adequate rest can degenerate through the stages of tendon pathology. Excessive tendon loading with poor management could ultimately lead to tendon rupture.

Therefore, there may be a case for decreasing tendon load in order to restore a pathological tendon back to health. The Alter-G ‘Antigravity’ Treadmill (Alter-G Inc., Fremont, CA) is a tool that can be used to decrease load on the lower body using a technology called Lower Body Positive Pressure (LBPP). Unloading of the original body weight can be adjusted from 100% down to 20% body weight with decrements of 1%. Previous research has noted a decrease in ground reaction forces and muscular activation when comparing the Alter-G treadmill to standard treadmill use.

To assess tendon structure several imaging tools can be utilised such as ultrasonographic tissue characterisation (UTC). Four validated echotypes can be identified, based upon the stability of intensity and distribution on contiguous transverse images, and related to tendon integrity with UTC imaging. Echotypes I and II refer to more intact and organised tendon bundles. Echotype III refers to a more fibrillar and disorganised tissue structure; and echotype IV represents an amorphous matrix that is largely composed of fluid. Load dependent tendon tissue structure changes

https://doi.org/10.1016/j.jsams.2017.11.007
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may be able to be monitored with UTC technology. Previous UTC imaging research\(^6,10\) has observed acute (<72 h) transient changes in tendon structure where tendon responses to a maximal load (elite sporting match) were measured. Slightly disorganised echotype structures were observed two days after the loading bout which returned to baseline after four days.

Prior UTC research that has observed changes in Achilles tendon structure has been performed on trained subjects with maximal loads.\(^9\) It is assumed that the Achilles tendons of novices will respond with similar changes in tendon structure as a result of sub-maximal loading due to the fact that untrained or novice exercisers respond well to most training protocols.\(^11,12\) Therefore, acute tendon deformation/degeneration may be studied during loaded and unloaded treadmill running in novice runners with UTC technology.

The aim of this study was to observe the changes in Achilles tendon structure in novice runners, with loading prescriptions of high load (HL) at 100% body weight compared to low load (LL) at 20% body weight. The hypothesis was for a transient change in echotype II after the HL running bout, corresponding to an increase in echotype II two days after the HL run which would return to baseline at seven days post run. There was no change expected to be seen after the LL run.

2. Methods

<table>
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<td>Age (years)</td>
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<tr>
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<tr>
<td>Height (m)</td>
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<td>BMI (kg/m²)</td>
<td>24 ± 3</td>
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<table>
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<tr>
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Twelve male and eight female healthy novice runners were recruited to participate voluntarily in the study (Table 1). Participants were included if they had no more than limited previous experience with running. Limited experience was defined as a participant that had not followed a structured running programme in the past twelve months and had not run more than one time per week in the past three months. Participants were excluded if there was suspicion of lower limb musculoskeletal injuries or absolute contraindications to exercise testing according to the American College of Sports Medicine (ACSM) guidelines for exercise testing and prescription.\(^13\) The protocol was approved by the Medical Ethical Committee of the University Medical Center Groningen (2016/039), all participants provided written informed consent.

The study employed a randomised crossover design. All participants participated in two separate running bouts and had six UTC scans taken. Running bouts consisted of one of high load (HL) on a standard treadmill (Technogym Excite, Gambettola, Italy) at 100% body weight, and one of low load (LL) on an Alter-G treadmill (Alter-G Inc., Fremont, CA) at 20% body weight. As the Alter-G treadmill is rarely used in practice with HL stimulus the standard treadmill was employed to approximate current best practice. The order of running bouts was randomised; half of the participants (group 1) performed the first running bout (RUN1) on the Alter-G treadmill and the second running bout (RUN2) on the standard treadmill. With the other half of the participants (group 2) the order was switched. UTC measurements were taken on both Achilles tendons of all participants on six occasions (UTC scan 1–UTC scan 6). These scans were performed immediately prior to RUN1 (day 0), 2 days post RUN1 (day 2), and 7 days post RUN1 (day 7). Participants then had seven rest days before participating in RUN2 (day 14) on the alternate treadmill. UTC measurements were again taken immedi-

ate prior to RUN2 (day 14), 2 days post RUN2 (day 16) and 7 days post RUN2 (day 21). This design was chosen due to the known physiological changes in tendon tissue structure post loading. There is an acute upregulation of collagen expression and an increase in synthesis of collagen protein, the degree of change is likely related to the amount of strain the resident fibroblasts experienced. The increased collagen development remains elevated for roughly 72 h post loading.\(^14\) The UTC scan on day 2 was hypothesized to capture these changes and by day 7 the change was expected to have returned back to baseline levels. Minor changes in the testing protocol had to be made to accommodate to personal circumstances of some participants (UTC scan post running bout performed a day after the day it was originally scheduled). Training logs of all physical activities engaged in from day 0 to day 21 were completed. Participants were requested to refrain from running during the testing period.

The intervention consisted of a 20 min running bout on the prescribed treadmill after a 5 min walking warm-up. Male participants started the run at 8 km/h; female participants started the run at 6 km/h. Participants ran at an RPE of 3–5 on the modified BORG scale,\(^15\) this was assessed every minute until the participant was within the desired range. Once participants were within this range RPE was assessed every 5 min to ensure participants stayed within the range. If RPE exceeded 5 then speed was decreased by 1 km/h; if RPE was lower than 3 then the speed was increased by 1 km/h.

Achilles tendon structure was quantified using the UTC imaging tool by a single experienced technician (LMR). Analysis of UTC output may incorporate a degree of subjectivity. To minimise this effect images were coded to identify subjects and time points, and analysed at a later date. A 7 MHz to 10 MHz linear ultrasound transducer (SmartProbe 12L5-V, Terson 2000+; Teratech; Burlington, Maryland, USA) was mounted in a tracking device (UTC Tracker, UTC Imaging, Stein, The Netherlands) that moved automatically along the Achilles tendons long axis over a distance of 12 cm recording regular images at intervals of 0.2 mm. The tracking device standardised transducer tilt, angle, gain, focus and depth.

Coupling gel was applied between the skin, an integrated standoff pad of the tracking device and the transducer to optimise contact prior to scanning. Participants were positioned in a prone lying position on a treatment table with the ankle in maximal passive dorsiflexion.\(^16\) The tracking device was placed on the posterior surface of the Achilles tendon parallel to the long axis of the tendon. The transducer was aligned with the Achilles insertion point at the calcaneus. Scan data was collected in a distal to proximal direction. The recorded images were stored and used to reconstruct a 3D ultrasound data block via the UTC software (UTC version 1.05, UTC Imaging). The UTC algorithm quantified echotypes across a rolling window of 25 continuous images (4.8 mm).

UTC is a tool which can quantify tendon structure based upon echotype stability.\(^17\) Furthermore, it is able to discriminate between symptomatic and asymptomatic tendons of Achilles tendinopathy patients.\(^8\) Symptomatic tendons have been shown to have higher percentages of echotypes III and IV, when compared to asymptomatic tendons.\(^8\) High reproducibility and excellent intraobserver reliability has been reported with UTC (ICC > 0.92) in trained observers.\(^8\)

Tendon structure was quantified by selecting a 2 cm section of the mid-portion of the Achilles tendon in the sagittal plane for analysis. This section was measured from 2 cm proximal to the upper border of the calcaneus in a proximal direction. This type of mid-portion Achilles tendon analysis has been performed in previous research.\(^9\)

Generalised estimating equations were used to test for change of echotypes I–IV for UTC scans 1–3 and 4–6. Separate models were run for each of the four echotypes with the echotype as the dependant variable. Participant (ID number) and group were used
as subject variables. Leg condition (treadmill type) and time (UTC scan) were used as within subject factors. Main effects of group, time, condition and gender were determined. An interaction effect of time and condition was determined. An exchangeable working correlation matrix was used. A series of t-tests were used for post hoc analysis. All analyses were performed using SPSS Statistics (version 22) with alpha set at 0.05.

3. Results

The percentages of each echotype I–IV for baseline, two days post run and seven days post run can be seen in Table 2. There was no significant difference in any of the four echotype percentages as a result of the LL or HL running bouts. The interaction effect of time and condition was not found to be significant for echotypes I–IV, respectively.

Additionally, there were no significant effects found for group, condition or gender for any of the four echotypes (Table 2). Significant effects of time were found for echotypes III and IV only. Post hoc analyses for echotype III showed that the significant difference was between baseline and 2 days post [Wald chi-square = 4.387, d.f. = 1, P = 0.036]; and between baseline and 7 days post [Wald chi-square = 6.792, d.f. = 1, P = 0.009]. Post hoc analyses for echotype IV showed that the significant difference was between baseline and 7 days post [Wald chi-square = 6.244, d.f. = 1, P = 0.012].

UTC baseline values were found not to differ between the two order groups; there was no significant difference between UTC scan 1 (mean ± SD 80.97 ± 4.98; 15.76 ± 3.79; 1.56 ± 1.35; 1.71 ± 1.72) and UTC scan 4 percentages (mean ± SD 80.45 ± 4.69; 16.35 ± 4.04; 1.52 ± 1.42; 1.67 ± 2.00) for echotypes I, II, III or IV respectively; t (77) = 0.470, p = 0.640, t (77) = 0.671, p = 0.504, t (77) = 0.136, p = 0.892, t (77) = 0.091, p = 0.928.

Participants mean velocity on the HL running bout was 7.8 km/h (range 6–11 km/h). Mean velocity on the LL running bout was 8.4 km/h (range 6–16 km/h).

4. Discussion

Although previous research with UTC technology has reported acute transient changes in echo type structure after high loading bouts there is no current information on the sensitivity of the device therefore a level of caution should be taken when interpreting results of this study. The results of this study show that there were no load dependent changes in echotype characteristics of novice runners after a high or low load running bout on two different motor driven treadmills. The hypothesis that an increase in echotype II would be seen in the acute phase after a HL run was based upon previous research in Australian Football League (AFL) athletes. Rosengarten et al. showed that after the high load of an entire AFL match in professional athletes, Achilles tendon structure showed an increase in echotype II, from a median of 6.9 pre match, to 8.6 two days post match. These values returned to baseline four days after the match. The study in AFL players placed the Achilles tendon under maximal load as opposed to the present study. The present study involved a HL run for 20 min in which participants ran ~3 km at an average RPE of 4 on the modified BORG scale. In an AFL match, regardless of playing position, players run ~12 km per game. The average load for a single AFL match has been recorded at 856 arbitrary units (au) (session-RPE multiplied by duration in minutes) compared to 80 au that was found in the HL run of participants in the present study. This metric has been shown to be a valid and reliable method of measuring internal training load with session RPE and summated heart rate zone score correlations ranging between r = 0.75 to 0.9. The HL stimulus in the present study may not have been high and/or long enough to elicit a response in the Achilles tendon characteristics measured.

Another study also found no change in Achilles tendon structure after a running bout in recreational runners: A possible explanation for this phenomenon may be attributed to the load of the exercise bout. The participants in the study were recreational runners who regularly ran bouts of 5 km; the exercise loading of a single 10 km run may not have been high enough to elicit a tissue response. The load in the current study is lower than in the study of Wong et al.; in the current study participants ran ~3 km compared to 10 km. Change was still expected to be found because of different participant characteristics. The present study tested novices compared to recreational runners; untrained or novice exercisers respond well to most training protocols compared to their more experienced counterparts. Another study reported no change in patellar tendon structure in volleyball athletes after 5 days of cumulative loading during a tournament. This study quantified objective load in a different manner to the present study therefore no direct comparison can be drawn with respect to load, but overall the volleyball tournament was subjectively perceived as high load for the knees of the athletes. The study quantified load by a subjective self report global rating of change scale. This scale compared the past week of physical activity loading on the knee to the previous 3 months. This was the first UTC study conducted on the patellar tendon; a possible reason no change in tendon structure was found, even though high loads were applied, is that the patellar tendon may require different loads to stimulate change in tendon structure in comparison to the Achilles tendon.

In addition to the above, participant and baseline echotype characteristics vary between the mentioned studies which may explain some differences in findings; Rosengarten et al. examined a male only group of young professional athletes with 92.3, 6.9, 0.22 and 0.53 found as the median percentages for echotypes I–IV respectively. The study of Wong et al. studied a middle-aged mixed gender group of recreational runners with Type 1 Diabetes Mellitus with ~90, ~6, ~0.2 and ~0.5 found as the median for echotypes I–IV respectively. The study of van Ark et al. studied a mixed gender group of adolescent volleyball athletes with means of 58.7, 39.4, 1.6 and 0.3 found for echotypes I–IV respectively. Finally the present study included a mixed gender group of young novice runners with means of ~81, ~16, ~2 and ~2 found for echotypes I–IV respectively.

Although previous research has found significant differences in echotypes as a result of load, the changes they observed are within 2% for echotypes I and II. Similar small scale changes of echotypes I and II were also observed in the current study which did not prove to be significant. The difference in findings between the studies is possibly due to different statistical analyses that were employed.

Further points of consideration are body positions during scans and UTC models. Some authors have positioned participants in a lunge position during UTC scans, others have employed the same prone lying position as the current study. Previous research with UTC have used an older UTC model (SmartProbe 10L5, Terason 2000; Teratech, USA) compared to this study and the study of van Ark et al. Direct comparison of the results of UTC studies should only be performed if the same UTC model and body positions were used during scans.

The finding of a time effect for echotypes III and IV was unexpected and showed both echotype percentages decrease over time. These findings imply that tendon structure shifts from less (echotypes III and IV) to more stable echo patterns (echotypes I and II). This increase in stability is reasonable, as forty-eight hours post exercise collagen synthesis is higher than degradation. Thus, with an increase in collagen synthesis, there is an increase in crosslinking of the collagen molecules improving the integrity of tendon fibrils. This increase in integrity may be translated to increased stability of
Table 2
Echotype (I–IV) percentages of the low load and high load running bouts for baseline, 2 days post run and 7 days post run; and results of the analyses for time*condition, group, time, condition and gender for each of the four echotypes.

<table>
<thead>
<tr>
<th>Group</th>
<th>Echotype I (81.0 ± 4.98)</th>
<th>Echotype II (15.8 ± 3.79)</th>
<th>Echotype III (1.6 ± 1.35)</th>
<th>Echotype IV (1.7 ± 1.72)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low load</td>
<td>81.0 (4.98)</td>
<td>15.8 (3.79)</td>
<td>1.6 (1.35)</td>
<td>1.7 (1.72)</td>
</tr>
<tr>
<td>High load</td>
<td>80.8 (5.57)</td>
<td>16.3 (4.61)</td>
<td>1.3 (1.25)</td>
<td>1.3 (1.22)</td>
</tr>
<tr>
<td>Baseline % SD</td>
<td>80.5 (4.67)</td>
<td>16.3 (4.04)</td>
<td>1.5 (1.42)</td>
<td>1.7 (2.00)</td>
</tr>
<tr>
<td>2 days post %</td>
<td>82.1 (4.24)</td>
<td>15.3 (3.46)</td>
<td>1.2 (1.13)</td>
<td>1.3 (1.29)</td>
</tr>
<tr>
<td>7 days post %</td>
<td>82.0 (4.54)</td>
<td>15.8 (3.69)</td>
<td>1.1 (0.97)</td>
<td>1.1 (1.08)</td>
</tr>
</tbody>
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* Wald chi-square 2.888 1.385 4.190
** P value less than 0.05.

- Echo patterns on imaging. This improvement of tendon structure on imaging is also supported by previous research that showed a single bout of exercise leads to beneficial tissue adaptations.25 It is important to highlight that the small change found, irrespective of load, may be attributed to rest and recovery. Although rest periods between measurements were included to single out the effect of the intervention load, rest itself may have had an influence on echotypes III and IV. There could be a benefit of low to moderate loads on tendon structure, in which minimal loads decrease the percentages of echotypes III and IV, thus potentially improving tendon organisation.

A potential limitation of this study is that some participants were physically active during the study, based on training logs, and engaged in strength training in addition to cycling as a means of transport. Cycling in combination with strength training may increase the capacity of the Achilles tendon to tolerate load. This may require a greater load to elicit the transient response in the Achilles tendon that was hypothesised. As UTC sensitivity has not been previously measured, conclusions should be treated with caution.

5. Conclusion

No difference in Achilles tendon structure response after a high or low load stimulus was found. The high load applied in this study seems to have been too low to elicit a load dependent response in Achilles tendon structure. The decrease in echotypes III and IV suggest that low to moderate loads can be applied to the Achilles tendon without compromising tendon structure. Further studies in this area should focus on protocols with higher loading and/or repetitive loading in athletic populations with and without Achilles tendinopathy to assess any differences in tendon structure.

Practical implications

- The two adopted training protocols seem safe for the tendon structure of novice runners between the ages of 18–30.
- Low to moderate loads seem to have no negative effects upon Achilles tendon structure of novice runners as determined with echotype percentage changes.
- Low to moderate loads may be beneficial in the treatment, management or rehabilitation of Achilles tendinopathy.

Acknowledgements

LMR was supported by CNPq, National Council for Scientific and Technological Development, Brazil. The authors would like to thank all participants for their cooperation and support from the organisation Medisch Centrum Zuid, Groningen, the Netherlands.

References