



Achilles Tendon Cross Sectional Area Changes Over a Division I NCAA Cross Country Season

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ABSTRACT

International Journal of Exercise Science 10(8): 1226-1234, 2017. Tracking Achilles tendon cross sectional area (CSA) changes may help clinicians understand exercise adaptations and Achilles tendon injury mechanisms. To track adaptations in the Achilles tendon in response to a cross country season. **Design:** Longitudinal study. Musculoskeletal (MSK) ultrasound images were obtained in a research laboratory. Cross country athletes ran with no restrictions outdoors and indoors. Participants were Division I NCAA cross country athletes (N = 24, age = 19.9 ± 2.1 years, mass = 61.32 ± 20.16 kg, height = 168.92 ± 17.16 cm, sex = 8 males and 16 females). Achilles tendon CSA was obtained through MSK ultrasound imaging at a pre-season baseline measurement, every 3 weeks throughout the season, and at post-season for a total of 4 measurements. Participants followed their normal running regimen outlined by their cross country coach. The dependent variable was Achilles tendon CSA measured by ultrasound imaging. We used a repeated measures ANCOVA to determine differences in CSA over the cross country season. CSA increased from baseline (0.439 ± .081 cm), to 0.466 ± 0.096 cm at 3-weeks, to 0.471 ± 0.092 cm 6-weeks, and decreased to 0.451 ± 0.104 cm at the post-season measurement. The 3-week and 6-week measures significantly increased from baseline ($F_{3,72} = 8.575$, $p < .001$). Achilles tendon CSA increased during the cross country season, but returned to baseline values at the end of a cross country season. Clinicians should be aware of the changing nature of the Achilles tendon CSA when treating cross country runners.

KEY WORDS: Tendon remodeling, tendon hypertrophy, Achilles tendinopathy

INTRODUCTION

Tendons are able to adapt their properties to meet the needs placed upon them (7, 15, 20). The Achilles tendon cross sectional area (CSA) has increased in response to an increased load during military training (13). A heavy loaded exercise regimen led to mechanically stronger and hypertrophic tendon in an animal model (20). These examples of tendon remodeling and adaptation indicates a metabolically active tissue, especially during exercise, that enables tendons to interact with muscle and contribute to muscle performance and movement (12).

The cause of tendon remodeling in response to running, leading to changes in Achilles cross sectional area (CSA), is still speculated because of conflicting research findings. Running has caused Achilles tendon CSA to increase (12), decrease (14, 19), and remain unchanged (5). However, subject population, running conditions, and running distances varied in these studies. Magnusson et al (12) showed that habitual runners have a larger CSA of the Achilles tendon compared to non-runners. Decreases in Achilles tendon CSA were found in experienced runners immediately after running on a treadmill for 10 minutes of different grades (14). A decrease in Achilles tendon CSA was also found in marathon runners with images taken directly after finishing a race (19). In the same study, the runners had recovered to pre-marathon Achilles tendon CSA 2-weeks post marathon (19). Achilles tendon CSA remained unchanged in a 9-month training protocol for untrained runners (4), where MSK ultrasound images were taken after the participants had not run for at least 24 hours. These differences of findings have made it difficult to determine longitudinal Achilles tendon CSA adaptations in response to running.

Achilles tendon injuries have not been correlated to tendon size changes, but tissue degeneration and CSA changes have been noted in another human tendon. In elite volleyball athletes, Jumper's knee was correlated with collagen bundle disorganization indicating tendon degeneration. The degeneration and subsequent repair of the patellar tendon led to increased tendon CSA (9).

Patients who have had an injury associated tendon degeneration often do not complain of pain until after tendon damage has occurred (1). When it is estimated 52% of distance runners will sustain an Achilles tendon injury during their career (8), it would be important for clinicians to differentiate between tendon remodeling and tendon degeneration. Continuing to understand Achilles tendon CSA changes may further alert a clinician to positive exercise adaptations or initial degeneration and repair of tendon tissue.

The purpose of this study was to track Achilles tendon CSA changes in a single population, NCAA Division I athletes, during a cross country season. A longitudinal study in elite runners has not been conducted to determine the extent Achilles CSA changes over a season. We hypothesized that Achilles tendon CSA would increase over the season due to positive tendon adaptations from chronic running.

METHODS

Participants

Twenty-four NCAA Division I cross country athletes (age = 19.88 ± 2.12 , mass = 61.32 ± 20.156 kg, height = 168.92 ± 17.1636 , sex = 8 males, 16 females, years of experience = 6.44 ± 5.54 years, years run collegiately = 2.56 ± 1.54 years) volunteered for this study. Before enrollment, participants were screened for inclusion or exclusion from the study. Participants were included if they were a NCAA Division I cross country athlete. Participants were excluded if they had a lower extremity injury within 2 months of study enrollment that had limited their regular activities for more than a week or if they had reported Achilles tendon pain at baseline.

The study methods were reviewed and approved by the Institutional Review Board (IRB) before data collection occurred. At study enrollment, each participant was given time to review and sign the IRB approved informed consent form.

Protocol

Before enrollment into the study, participants ran on their own during the summer and did not follow a prescribed running program determined by their coach. During the summer months participants likely ran 1-2 times per day, 4-5 days per week. The cross country season was defined as the end of August to the end of October. For a third of the runners the cross country season extended to the middle of November. Throughout the season, participants ran as prescribed by their coach, which was typically two times a day and 5-6 days a week.

Once enrolled in the study, potential covariates were measured through simple interview questions and basic measurements. Participants' age, sex, years running total, and years running at the collegiate level were asked. Height and mass were determined using a standard wall measuring tape and scale, respectively. Body mass was measured at each visit throughout the study.

Participants reported for baseline MSK ultrasound imaging the last week of August, two weeks before their first official race. For every image, participants did not run for at least 4 hours prior to the image being taken, but had run within 24 hours of the image. Images were usually taken before practice and were performed at a similar time of day. The participant would lay prone on a treatment table with their ankle positioned at the anatomical position 0°, measure by a goniometer. A strap was connected to the end of the table in which the participant would rest their foot against. The clinician placed ultrasound transmission gel on the ultrasound transmission head and placed the 12 MHz linear ultrasound probe at the midpoint between the medial and lateral malleoli (Figure 1).



Figure 1. Cross sectional MSK imaging of the Achilles tendon. Musculoskeletal ultrasound imaging was performed with the ankle the anatomical position 0°. The ultrasound transducer was placed directly between the medial and lateral malleoli. Similar methods were used for each Achilles tendon CSA image recorded.

All images were recorded with the GE Logiq e ultrasound (GE Healthcare, Chicago, IL) using the ankle MSK preset. The image depth was set to 2 cm and the focus position set to 0.25 to

0.75 cm. At each of the 4 visits, 2 cross sectional images of the Achilles tendon were recorded and saved for both the right and left legs (i.e. 4 images total at each session). We followed this same procedure for recording images on both legs. The same investigator imaged all Achilles tendons. The imaging investigator, a licensed athletic trainer, received sonography training in a separate research laboratory before taking images for this study. All images were measured using internal software on the GE logiQ e.

Four images were recorded during the study (Baseline, 3-weeks, 6-weeks, and post-season. Participants Achilles tendons were re-imaged every 3 weeks in the middle of the season. At the conclusion of the season, the last image was recorded within 3 days of their last race. Sixty five percent (16/23) of participants finished their season with the conference championship meet, which was 3 weeks after the 6-weeks measurement. The post-season measurement was not specifically 3 weeks for all runners. Thirty-five percent (8/23) of participants competed in the regional meet, which was 5 weeks after the 6-week measurement.

Participants were asked immediately after the ultrasound image was captured if they had pain within their Achilles tendon, during rest or running. Participants rated their pain on a numeric pain rating scale (NRS) of 0-10 with 0 meaning no pain whatsoever and 10 being that their Achilles hurt so much they could not function. Participant verbalized their pain score to the investigator. Pain was assessed using the NRS at each visit throughout the study.

At the conclusion of the season and all of the data collection, two investigators measured the Achilles tendon CSA of all images. The two images' CSA measurement at each time point for the right or left tendon were averaged together. The right and left Achilles tendons were measured separately and both included separately in the statistical analysis. Both investigators were blinded to participant and time point of the image. Reliability between investigators measuring Achilles tendon CSA was analyzed in a pilot study before participants were enrolled for this study (ICC = 0.998, SEM = 0.008).

Statistical Analysis

We used a repeated measures ANCOVA to determine how the Achilles tendon CSA changed during the season. Potential covariates analyzed included: age, sex, height, mass, years run, years run collegiately. Potential covariates were included in the analysis to determinant significant CSA changes between time points when adjusting for potential variables that may also play a role in Achilles tendon CSA size differences between participants. Descriptive statistics for Achilles tendon pain was analyzed. Statistical analysis was performed using JMP Pro 12 (SAS Inc., Cary, NC) and alpha was set at $P < 0.05$.

RESULTS

One participant out of 24 did not complete the study. The participant had a lower extremity injury (non-Achilles tendon) that limited his running. Therefore, we had a 95.8% (23/24) completion rate. All participants were compliant to their coaches running prescriptions and to the studies MSK ultrasound procedures. Achilles tendon pain was reported by 3 out of 24

athletes. For all 3 athletes, pain was only reported at the final post-season measurement with a mean score of 4.3 ± 1.5 out of 10.

Achilles tendon CSA significantly increased in the middle of the cross country season (time points 3 weeks and 6 weeks), but there was no difference between the post-season and pre-season size ($F_{3,72} = 8.847, p < 0.0001$) (Figure 1). Sex ($p = 0.006$) and mass ($p = 0.002$) were significant covariates during the analysis.

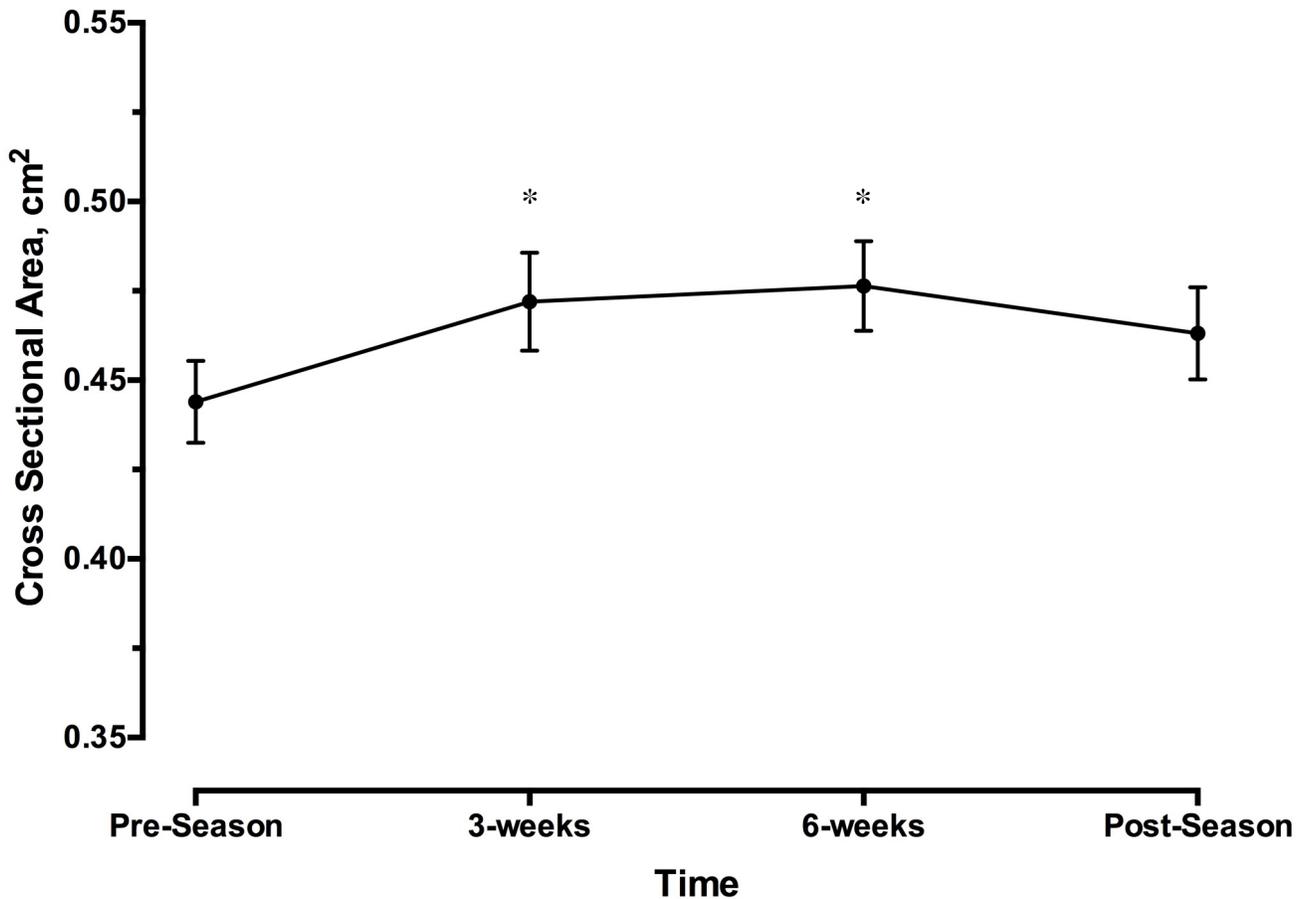


Figure 2. Achilles tendon cross sectional area over a NCAA Division I cross country season. Mean \pm 1 SE Achilles tendon CSA at pre-season, 3-weeks into the season, 6-weeks into the season, and immediately after the season (post-season). The CSA at 3-weeks, and 6-weeks, were significantly greater than the pre-season and post-season areas ($p < 0.0001$).

DISCUSSION

The aim of this study was to determine differences in CSA over the course of a cross country season. Using MSK ultrasound imaging, we successfully tracked Achilles tendon CSA and found that CSA does significantly change in response to a cross country season in NCAA Division I runners. We hypothesized that Achilles tendon CSA would steadily and slowly

increase over the course of the cross country season. However, Achilles tendon CSA increased at weeks 3 and 6 in the season but returned to near baseline value at the end season.

Tendon hypertrophy occurs in response to increased load (13). Elite infantry units Achilles CSA increased during a 6-month training protocol as their exercise load increased (13). If we assume that our runners increased their running load through the first two-thirds of the season it would account for the tendon hypertrophy. Tapering is the process of gradually decreasing miles towards the end of a season so that runners are ready for bigger events. Tapering is practiced by many cross country athletes. Decreased Achilles tendon CSA, seen towards the end of our season, may be due to tapering and a decrease in load. Due to a study limitation, we unfortunately did not track running millage or time in our athletes making it difficult to make a direct comparison of running load and Achilles tendon CSA. We can not be certain that tapering is the exact reason for our decrease in Achilles CSA because previous research has also shown that tendons maintain a consistent CSA and show no atrophy despite being immobilized for up to seven weeks (3). Making a correlation between running load and Achilles tendon CSA, could explain the increased and decreased CSA changes throughout the season. Further research needs to determine if there is a correlation between load and CSA, and then further determine running load's correlation to potential Achilles tendon injury.

Another potential rational for the decrease in Achilles tendon CSA at the end of our season, is the continued stress on the tendon over the season may cause Achilles tendon thinning and breakdown. In at least two studies (14, 19), significant decreases in Achilles tendon CSA occurred directly after the athletes were finished running. The Achilles tendon stretches and thins over the course of a single running activity, decreasing its CSA (10). Our participants did not run 4 hours prior to their MSK ultrasound images to limit the potential for this immediate thinning to confound our data. Acute daily stretching and thinning of the Achilles tendon over the cross country season could potentially create a decrease of the CSA toward the end of the season. Future studies should determine if tendon thinning could be a precursor to tendon injury.

Hansen et al (4) found no difference in Achilles CSA from the start to end of a 34-week term running training program. Hansen et al (4) did not take serial measurements throughout their study and tapering did not occur in their recreational athletes. Chronic running leads to Achilles tendon adaptation and the Achilles tendon becomes more efficient to the continual stress placed upon it. Achilles tendon mechanical properties are similar between individuals with different activity loads even though differences occur in CSA size (16). Running can create morphological changes within the Achilles tendon making the tendon more stiff and efficient for running (5, 6). As the athletes continue their season, the tendon mechanical properties potentially improve, leading to the tendon to be more efficient. The improvement of tendon properties and constant exercise may allow for the tendon to remodel to a stronger version toward the end of the season (2, 18).

The iceberg model for tendon injury may help understand why tendon CSA changes could influence the prevention and treatment of Achilles tendon pathologies. The iceberg model

shows that (1) initially micro-damage occurs in a tendon due to various overuse conditions. The tendon responds by initiating healing factors. If healing is overwhelmed by additional tendon injury more micro-damage occurs starting the tendinopathy cascade pathway. Neoangiogenesis occurs, starting the injury cascade, but the individual is still pain free. It is only after repeated stress and overload that the individual feels pain. The sensation of pain is only the tip of the iceberg and tendon damage has already occurred. The ability to determine degenerative changes before pain is felt in tendinopathy conditions could lead to early prevention methods before pain and injury occur. Being able to forecast tendon changes in elite runners and seeing abnormal variances may alarm clinicians that damage is occurring at the tendon. Clinicians would be able to initiate therapeutic interventions before the athlete feels pain and/or before extensive tissue disorganization has occurred.

Our study is limited by measuring only Achilles tendon CSA and a few covariates. Future research should be conducted to answer questions that our study did not answer. First, additional variables such as, running miles and/or running time should be used to identify the direct relationship between running load and Achilles tendon CSA changes. Second, the mechanism of tendon adaptation during, directly after and over a period of time should be further investigated. Lastly, changes of Achilles tendon CSA to injury rates needs to be determined. Determining a non-invasive method to predict Achilles tendon injury, such as using MSK ultrasound imaging, would prove vital to health care clinicians. Our study was a step in determining if a change of the Achilles tendon does exist in elite cross country runners.

The main assumption of this study is that Achilles tendon CSA is a reflection of Achilles tendon remodeling and/or degradation. We also assume that Achilles tendon remodeling is a reflection of each individual person, and that their own characteristics play a distinct role in how their Achilles tendon adapts.

Our study is delimited by enrolling only NCAA Division I cross country athletes and the results should only be generalized to collegiate runners. We assumed all athletes followed the protocol and complied with the instructions to not run 4 hours prior to taking their MSK ultrasound image. However, we did not limit their other normal daily activity before the scheduled imaging time.

During the course of a NCAA Division I cross country season Achilles tendon CSA increased significantly for a portion of the season but returned to baseline values at the end of the season. Fluctuations in Achilles tendon size may be a normal adaptation to the stresses of a cross country season, but may have injury consequences. Further investigation of Achilles tendon changes and injury rates should be conducted.

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