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Original Research

Thermal profiles over the Achilles tendon in a cohort of non-injured collegiate athletes over the course of a cross country season

Steve Tumilty [a, *], Divya Bharatkumar Adhia [a], James M. Smoliga [b], Angela Spontelli Gisselman [b]

[a] Centre for Health, Activity and Rehabilitation Research, Otago University, Dunedin, New Zealand
[b] Department of Physical Therapy, High Point University, High Point, NC, USA

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ABSTRACT

Objectives: To determine normal temperatures over the Achilles tendon over nine weeks.
Design: A prospective cohort study with nine weeks of observation.
Setting: University's Human Biomechanics and Physiology Laboratory.
Participants: Male or female competitive runners running at least 25 miles per week who did not report pain in the region of the Achilles over 9 weeks of data collection.
Main outcome measure: Thermal images taken at the same time and day of the week, were used to measure the temperature of the skin over the Achilles tendon.
Results: Seventeen athletes were eligible for analysis. The Achilles tendon temperatures were right 28.7 °C ± 1.3 °C, left 28.8 °C ± 1.3 °C. ICC demonstrated a very high consistency and minimal variations in temperatures (right 0.86 (95% CI = 0.58, 0.98), left 0.79 (95% CI = 0.38, 0.97). The mean difference between sides over the season was 0.50 °C ± 0.43 °C ($p = 0.681$). A decreasing trend in the Achilles tendon temperatures as the season progressed was observed.
Conclusion: This is the first report of normal thermal profiles over an extended period. Variations in Achilles temperatures left to right, and over time were not significant. The decreasing temperature trend over the season warrants further investigation.

1. Introduction

Overuse injuries are common among both elite and recreational runners, a reported 59.4% incidence (Ristolainen et al., 2010), with the Achilles tendon being second only to the knee as the most commonly reported site of injury, 13.9% and 19.4%, respectively (van Poppel et al., 2014). Achilles tendinopathy is a complex condition with the relationship between structure, function and pain not yet fully understood. To help target treatments for this disorder, Cook, Rio, Purdam, and et al (2016) have proposed a continuum model describing reactive and degenerative phases which may lead to disrepair (Cook et al., 2016). A Dutch study estimated the incidence of Achilles tendinopathy in the 21–60 years old age group as 235/100,000 (de Jonge et al., 2011). Despite strong evidence supporting conservative management for the condition, up to 29% of patients receive surgical intervention indicating a failure to address one or more aspects of the healing and remodelling processes (Zafar, Mahmood, & Maffulli, 2009). Sympathetic nervous system (SNS) involvement has been identified as a component of tendinopathy with increased sympathetic innervation in paratendinous tissue, abnormal tenocytes producing catecholamines (Jewson et al., 2015), and effects on pain duration (Jewson et al., 2017, p. P18). The SNS can influence blood flow, pain, healing and remodelling through neuronal signaling (Ackermann et al., 2014; Dean, Franklin, & Carr, 2013). The skin temperature overlying a structure can directly reflect the underlying circulation and tissue metabolism and thus could be a surrogate measure of SNS activity.

Damaged structures have been shown to exhibit changes in temperature in both directions, see review by Chaudhry et al. (Chaudhry et al., 2016), with an increase in temperature being linked to inflammation, and a decrease to degeneration (Garagiola & Giani, 1990). Medical Infrared Thermography (MIT) is a non-invasive, safe method to measure changes in skin temperature

* Corresponding author. Centre for Health, Activity and Rehabilitation Research, Otago University, Dunedin, 9054, New Zealand.
E-mail address: steve.tumilty@otago.ac.nz (S. Tumilty).
@DrTphysio (S. Tumilty)

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(Hildebrandt, Raschner, & Ammer, 2010) with demonstrated reliability (Alfieri & Battistella, 2018; Dibai-Filho et al., 2015; Silva et al., 2018) aid in early detection of injuries. MIT has been used in animal athletics, such as in horses as a method to detect early signs of injury before becoming clinically relevant (Michelotto, Rocha, & Michelotto, 2016; Turner, Pansch, & Wilson, 2001), and with greyhounds to assess how the animals are coping with heat stress (Vainionpaa et al., 2012). In human populations, thermography has also been used in sports to study thermal responses during and after exercise (Hildebrandt et al., 2010; Marins et al., 2012; Merla et al., 2010), to control training loads (Fernandes et al., 2017), or to prevent injuries (Gómez-Carmona et al., 2011; Sillero-Quantana et al., 2011). The use of MIT for early detection of Achilles tendon injuries thus seems encouraging. However, for appropriate interpretation of the individual's thermographic patterns, the normal variation or the reference values of skin temperatures over the Achilles tendon as a competitive season progresses needs to be established.

Therefore, the aims of the present study were: a) to determine normal variability in skin temperature over the Achilles tendon during resting conditions in a cohort of collegiate cross country runners during the course of a competitive season who do not report symptoms of tendinopathy and, b) to determine any normal, within participant, side-to-side variations in the skin temperature over the Achilles tendon.

2. Methods

2.1. Study design and setting

A prospective cohort study with a three-month observation period was conducted at High Point University in High Point, NC, USA, from August 2016 to December 2016. All eligible and consented participants participated in their normal training regimen as prescribed by the coaches and support staff. The participant's training sessions were not altered in any way for the purposes of this study. Ethics approval for the study was obtained from the University of Otago Human Ethics Committee (Health) (Reference 16/075) and High Point University's Human Institutional Review Board (#201605-488).

2.2. Participants and recruitment

A convenience sample of 29 competitive distance runners participated in the study. Participants were recruited from May 2016 through early September 2016 with flyers and emails to students, college-sponsored athletes, and coaches; and through word-of-mouth. Male or female participants (aged 18–25 years) running at least 25 miles per week were eligible to participate in the study. Data from all the participants who completed the season without any report of pain in the region of the Achilles tendon were extracted for analysis. Exclusion criteria were any lower limb injury in the previous 6 months that would prevent them from participating in sport or training.

2.3. Procedures

Following written informed consent, each participant attended a 30-min testing session at the University's Human Biomechanics and Physiology Laboratory for nine consecutive weeks. Demographic, anthropometric, sport experience, and musculoskeletal injury data were gathered from each participant at the first session.

The FLIR T450SC (FLIR Systems Inc, Wilsonville, Or, USA) with a measurement range from −20 °C to +120 °C, 1% accuracy, sensitivity ≤0.05 °C, IR spectral band of 7.5–13 µm, refresh rate of 60 Hz, auto-focus, and a resolution of 320 × 240 pixels, was used to obtain the MIT photos. Emissivity was 95%. The images of posterior views of the lower limbs (calf muscles and Achilles tendons) were obtained on a weekly basis at the same day and time, (as close to waking as practical) for nine weeks during the cross country season. Prior to MIT, participants acclimatized to the lab conditions for 15 min. The ambient temperature and humidity of the room was recorded separately on each occasion and entered into the FLIR camera. During this acclimatization time, participants were seated on a chair and wore shorts and a shirt, but not socks or shoes. Images were taken in a designated area with non-reflective surfaces and screened on three sides to minimize airflow. Participants were instructed to stand on a raised platform with their heels on a line. The camera was positioned to be perpendicular to the area of interest and at a fixed distance of one meter. No alcohol, caffeine, smoking or exercise was permitted prior to the images being taken. During each week, the participants also completed a modified Oslo Sports Trauma Research Centre (OSTRC) overuse injury questionnaire, which was used to quantify the athlete-reported musculoskeletal symptoms and problems. Training load (arbitrary units, AU) was estimated after each training session using the formula: Training load (AU) = Session rating of perceived exertion (sRPE) * total training session duration (minutes). Runners' photos were grouped into those with no reports of any Achilles tendon problems (i.e. defined as a OSTRC overuse injury severity score of 0/100) and those with reports of Achilles problems. All injured participants had their MIT images removed from the data set.

2.4. Data reduction and statistical analysis

The MIT photos were exported to and analysed using FLIR Tools (FLIR Systems Inc.). The box measurement tool was used to define a standardised rectangle of 10 pixels wide by 40 pixels high. This tool was placed over the length and width of the Achilles tendons with the lower border of the box in line with the superior border of the

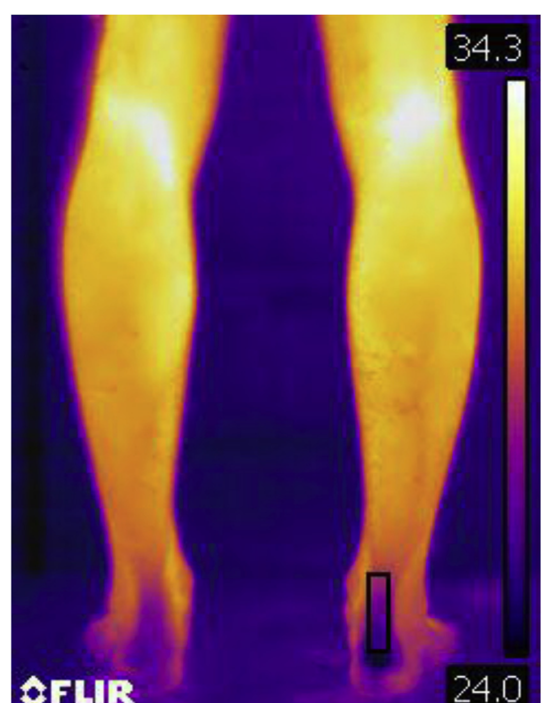

Fig. 1. Measurement of the average temperatures of the Achilles tendon using the box measurement tool, (indicator of placement of the tool).

calcaneus as defined by the change in color between the bone and the tendon and judged by the assessor (Fig. 1). A single tester analysed all the images and recorded the average temperatures of each of the Achilles tendons. This tester did not have any interaction with the participants.

All statistical analyses were conducted using Statistical Package for the Social Sciences (Version 23) (IBM Corp., 1989, 2015). Descriptive statistics including mean and standard deviations were computed for the demographic and the outcome variables. The variations in the Achilles tendon temperatures over the season were explored using the Intraclass Correlation Coefficient [ICC (2,k); two-way random, average measures, absolute agreement] and the standard error of measurement (SEM) [calculated as SEM = Standard deviation x Square root (1 − ICC)]. Minimal Detectable Change (MDC) was calculated using MDC = SEM x 1.96 × square root 2. A linear regression analysis using mixed models was used to determine the side-to-side differences (Field, 2013; Fitzmaurice et al., 2008). The participants were defined as random variables, and the sides and time were defined as fixed variables. The trend analysis was used to determine the direction of the changes in the Achilles skin temperature as the season progressed. The interaction effect for a linear trend (Side x week) was tested for statistical significance to determine the differences in trends between sides. Statistical significance was set at $p < 0.05$.

3. Results

Of the 29 athletes assessed, 17 athletes ranging in age from 18.1 to 25.2 years (mean 20.7, ±SD 2.3 years) reported no pain in the Achilles tendons over the data collection period and were eligible for the study. The 17 athletes provided 153 images in total for analysis over the 9 weeks. Ten participants (59%) were male.

Fig. 2 presents the descriptive statistics of the right and left Achilles temperatures over the season. The grand mean ± SD for the right and left Achilles tendon temperatures were 28.7 °C ± 1.3 °C and 28.8 °C ± 1.3 °C, respectively. The ICC demonstrated a very high consistency and minimal variations in the resting Achilles tendon temperatures over the 9 weeks, both in the right [ICC = 0.86 (95% CI = 0.58, 0.98)] as well as in the left [ICC = 0.79 (95% CI = 0.38, 0.97)] Achilles tendons. The SEM for the right and left Achilles tendon temperatures were 0.55 °C and 0.58 °C, respectively. The mean difference between the right and the left Achilles tendon temperatures over the 9 weeks was 0.50 °C ± 0.43 °C. The linear mixed model regression analyses demonstrated no significant side-to-side differences ($p = 0.681$) in temperatures between the right and the left Achilles tendons over the season. Fig. 2 demonstrates an overall decreasing trend in the Achilles tendon temperatures as the season progresses, irrespective of the sides; however, a non-significant relationship was demonstrated by the linear mixed models [Side x Week ($p = 0.924$)]. The mean ± SD ambient temperature of the laboratory over the nine weeks was 21.8 °C ± 0.46 °C (min 21.1 °C; max 22.4 °C). Relative humidity ranged from a minimum of 34.3% to a maximum of 56.5%, with a mean ± SD of 47.3% ± 8.1%.

The average training load (grand mean) for the cohort on a week by week basis is displayed in Table 1. This peaked at week 2 and was relatively stable until week 6.

4. Discussion

The current study is the first study to assess the skin temperatures over the Achilles tendon in a cohort of collegiate cross country runners during a competitive season. The results of the study indicated no significant differences in the resting Achilles tendon skin temperatures, either side-to-side or over the 9 weeks of assessment. This study also established baseline temperatures that correspond to an earlier study performed on runners that measured on three consecutive days and also reported no significant contralateral differences, and a mean temperature of the Achilles tendon of 29.5 °C (Sanz-Lopez et al., 2016), with any differences between the two studies being due to confounding factors such as issues of gender, race, and levels of fitness.

4.1. Importance of reduced skin temperature over the Achilles

An observation that warrants discussion is the decreasing trend in the Achilles tendon skin temperatures, irrespective of the sides, as the season progressed, i.e. the tendon became cooler as the season progressed. This observation, along with the findings of a study that reported 8.6% of injured military recruits exhibited regional hypothermia as compared to the contralateral side, that lasted from a few days to 6 weeks (Di Benedetto et al., 1996), may indicate that a decrease in temperature in some individuals may be an important observation. The findings may suggest activation of the sympathetic nervous system, resulting in vasospasm of the local microcirculation and subsequent decrease in local perfusion and a colder area (Sands, McNeal, & Stone, 2011); thereby indicating an altered physiological response which may increase injury

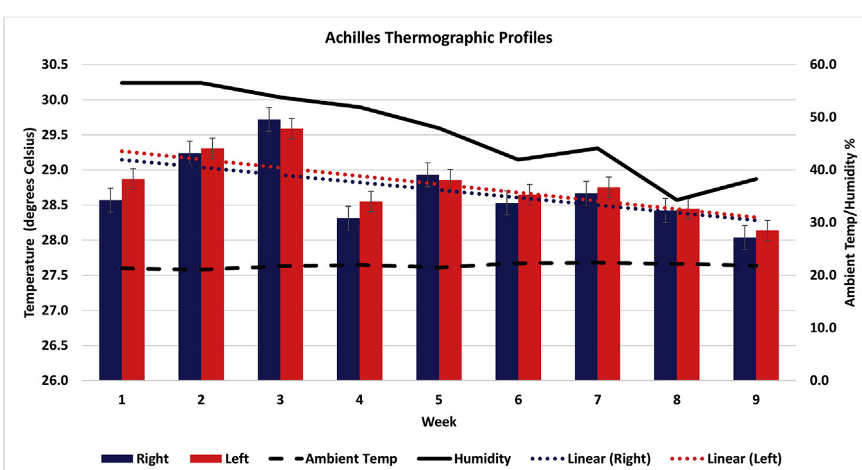

Fig. 2. Average temperatures of the Achilles tendon over the course of a season. Error bars represent standard error. Ambient Temp and Humidity are on right vertical axis.

Table 1
Average training load.

Week	1	2	3	4	5	6	7	8	9
Training load (AU)	306.4	327.1	298.0	307.3	303.5	272.2	238.2	212.1	267.1

AU = Session rating of perceived exertion (sRPE) * total training session duration (minutes).

probability as the season progresses. In a recent systematic review that included 13 studies, it was reported that abnormal tenocytes have the ability to self-produce catecholamines and that there was an increase in sympathetic innervation in the paratendinous tissue of painful tendons (Zafar et al., 2009). Whether these affects happen prior to the tendon becoming painful and at what level of concentration they become clinically relevant is unknown.

However, this trend of decreasing temperature as the season progressed comes with some caveats; first the amount of temperature reduction over weeks 3–9 may well be less than reported as the accuracy of our results would be affected by SEM (R 0.55 °C; L 0.58 °C). Increasing sample size would improve the accuracy. Second, the MDC (R 1.52 °C; L 1.61 °C) would indicate that the observed trend may not be meaningful at all, as the magnitude of change between weeks 3–9 fall on the border of this range. This association between the amount of temperature change and injury is unknown and will be a focus of future study.

Thermal bilateral symmetry can be described as the observation that the mean temperature of regions of interest in corresponding anatomical regions are similar, and is an important indicator of a normal thermal state (Brioschi, Macedo, & Macedo, 2003). Our results indicated a mean contralateral difference of 0.5 °C ± 0.43 °C between the right and left skin temperatures over the Achilles tendon and compare with a previous study by Zhu and Xin (Zhu & Xin, 1999) who reported a mean contralateral difference of 0.50 °C ± 2.53 °C in the skin temperatures over the heel. These values are slightly higher compared to the previous studies on healthy individuals; Uematsue et al. (Uematsu et al., 1998) and Zaproudina et al. (Zaproudina et al., 2008) reported a mean contralateral difference of 0.29 ± 0.21 °C and 0.21 ± 0.17 °C, respectively, in the posterior calf skin temperatures; whereas Marins et al. (Marins et al., 2014) reported a mean contralateral difference of 0.09 °C in Brazilian males and 0.15 °C in females in the dorsal calf skin temperatures. The variations in the contralateral differences could be attributed to the differing regions of interest. Although there might be clear overlaps between the regions (posterior calf), our study specifically focused on the skin over the Achilles tendon, when compared to the wider posterior calf region used in other studies. Furthermore, environmental factors such as ambient temperature, humidity and airflow during data collection, as well as various other factors such as limb dominance (Smith, Bandler, & Goodman, 1986), race or gender (Marins et al., 2014), sports (Arnaiz-Lastras et al., 2011, p. P107; Gómez-Carmona et al., 2009, p. P116), or physiological responses may have an effect on the thermal behaviour of each region of interest and consequently normal skin temperatures (Fernandez-Cuevas et al., 2015). Thus, larger population studies are needed to ascertain the influences of all the possible confounding factors on normal skin temperatures.

4.2. *Usefulness of thermal profiles*

The contralateral differences in the skin temperatures have been used as an indicator of the abnormality or predictive of future injury, where higher contralateral differences could indicate an imbalance or impairment between symmetrical parts of the body (Ben-Eliyahu, 1992; Turner et al., 2001; Vainionpaa et al., 2012). Several rigorous reference points have been set such as: 0.51 °C (Niu et al., 2001; Uematsu et al., 1998) or 0.67 °C (Uematsu et al., 1998) in the toe region, 0.64 °C (Zaproudina et al., 2008) in the heel region, 0.50 °C (Marins et al., 2014) in ventral hand and dorsal forearm in women, and 0.30 °C (Marins et al., 2014) in the dorsal forearm in men. Ben-Eliyahu (Ben-Eliyahu, 1992) in their study to detect sympathetic dysfunction in patellofemoral pain suggested that a contralateral temperature difference greater than 1.1 °C can be considered a strong indicator of abnormality; demanding further diagnostic protocols to identify the cause of the difference. Our results demonstrated that the maximum mean contralateral difference in the healthy Achilles tendon skin temperatures was 0.6 °C irrespective of the sides; which is consistent with the above studies and lower than the maximum contralateral temperature difference of 1.1 °C suggested by Ben-Eliyahu (Ben-Eliyahu, 1992). MDC of R 1.52 °C; L 1.61 °C would support our findings that the temperatures are stable over the 9 weeks of assessment as the observed drop in temperature over this period fell within the 95% CI range. However, further larger population studies need to be conducted in order to set the normative limit value for the contralateral skin differences over the Achilles tendon.

The current study has established the normal variations in the skin temperatures over the Achilles tendons in a cohort of collegiate cross country runners over the competitive season. This normative information could be of use not only to practitioners but also to sports physiotherapists and coaches who provide training to athletes. Further, the current study has also demonstrated the use of MIT in athletes to determine the thermal symmetry in the Achilles tendon. As MIT is a non-invasive, non-radiating, first-line detection modality, it could be used in sports medicine field as a pre-scan team assessment method (Hildebrandt et al., 2010). Future studies will explore the concept of thermal symmetry and the use of MIT technique to create sport specific databases for detection of athletes who may possibly go on to report pain, and perhaps aid in early intervention and prevention of injuries.

4.3. *Limitations*

The findings of the present study, although interesting, are not without some limitations. The Achilles tendon skin temperatures were recorded in a small sample of collegiate cross-country runners with an age range of 18.1–25.2 years and hence the findings of this study cannot be applied to individuals with disparate anthropometrics. Every effort was made to obtain thermal images at the same time of day, but this was not always possible. Thus, the time between previous training session and time of MIT photograph differed between athletes. Only the resting temperature of the skin over the Achilles was recorded, therefore the immediate/short term temperature response of the tendon to running load cannot be determined from this data. In Fig. 2 there was a clear increase in skin temperature over the Achilles up to week 3, right 1.1 °C left 0.7 °C, without any clear explanation. Apart from a spike at week 2, training load remained relatively constant from weeks 1–5 and then started to decrease, so any relationship in this regard is weak. In hindsight, more information around actual competition schedules and any other sporting activities may have given a better estimate of load on the tendon, and enabled a deeper analysis of this phenomenon.

5. Conclusion

This is the first study to establish resting skin temperature profiles over the Achilles tendon over an extended period of time. In healthy, uninjured collegiate runners, the temperature of the tendons remained stable, with no significant differences between left and right tendons, or from the beginning to the end of the season. The observed trend of a decrease in temperature over the tendon as the season progressed indicates an area for further investigation, as this may be an indicator of increasing sympathetic drive and a higher risk of future injury.

Ethical approval

Ethics approval for the study was obtained from the University of Otago's Human Ethics Committee (Health) (Reference 16/075) and High Point University's Human Institutional Review Board (#201605-488).

Subjects gave informed consent for the work.

Conflicts of interest

Declarations of Interest: none.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ptsp.2019.01.009.

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