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Biomechanical Factors Associated with Achilles Tendinopathy and Medial Tibial Stress Syndrome in Runners

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Running Title: Biomechanics Associated with AT and MTSS

Abstract

Background: There is disagreement in the literature regarding whether excessive excursion or velocity of rearfoot eversion is related to the development of two common running injuries: Achilles tendinopathy (AT) and medial tibial stress syndrome (MTSS). An alternative hypothesis suggests the duration of rearfoot eversion may be an important factor. However, duration of eversion has received relatively little attention in the biomechanics literature.

Hypothesis: Runners with AT or MTSS will demonstrate longer duration~~s~~ of eversion but not greater excursion or velocity of eversion compared to healthy controls.

Study Design: Cross sectional study.

Methods: 42 runners participated in this study (13 with AT, 8 with MTSS, and 21 matched controls). Participants were evaluated for lower extremity alignment and flexibility after which a three-dimensional kinematic and kinetic running gait analysis was performed. Differences between the two injuries and between injured and control participants were evaluated for flexibility and alignment, rearfoot kinematics, and three ground reaction force metrics. Binary logistic regression was used to evaluate which variables best predicted membership in the injury group.

Results: Compared to controls, injured participants demonstrated higher standing tibia varus angles (8.67° ± 1.79° vs. 6.76° ± 1.75°; $p = .002$), reduced static dorsiflexion range of motion (6.14° ± 5.04° vs 11.19° ± 5.10°; $p = .002$), more rearfoot eversion at heel off (-6.47° ± 5.58° vs 1.07° ± 2.26°; $p < .001$), and a longer duration of eversion (86.02 ± 15.65 % stance vs 59.12 ± 16.5 % stance; $p < .001$). There were no differences in excursion or velocities of eversion. The logistic regression ($\chi^2 = 20.84$, $p < .001$) revealed that every 1% increase in eversion duration during stance period increased odds of being in the injured group by 1.08 (95% confidence interval 1.023 – 1.141, p = .006).

Conclusion: Compared to healthy controls, runners currently symptomatic with AT or MTSS have longer durations of eversion but not greater excursion or velocities of eversion.

Clinical Relevance: Static measures of tibia varus angle and dorsiflexion range of motion, along with dynamic measures of eversion duration, may be useful for identifying runners at risk of sustaining AT or MTSS.

Key Terms: Period of pronation, Achilles Tendinopathy, Medial Tibial Stress Syndrome, running injuries

What is known about the subject: Excessive excursion or velocities of rearfoot eversion are commonly cited biomechanical factors thought to be related to the development of both AT and MTSS in runners. However, there is disagreement in the literature, with numerous studies documenting no differences in these parameters between injured and healthy runners.

What this study adds: This study examines the hypothesis that it is not the excursion or velocity of eversion which matter for AT or MTSS, but rather the duration of eversion. The results show that excursion and velocities of eversion are not different between injured and healthy runners, and that the duration of eversion is the best predictor of group membership. This study also identifies several variables, which are easily measured in clinical settings which are different between injured and healthy runners. These may potentially be useful in future studies identifying clinical screening for runners at risk to sustain AT or MTSS.

INTRODUCTION

Running is a popular recreational and fitness activity in which an estimated 19 million Americans engage.[41] Unfortunately, the injury rate among runners remains high, with epidemiologic studies reporting that between 25% and 75% of runners will sustain an injury in anyone one year period.[17,31,46] These injuries are predominantly due to overuse. Medial tibial stress syndrome (MTSS) and Achilles tendinopathy (AT) are two examples of such injuries, and have been consistently reported as among the five most common injuries sustained by runners.[21,27,47]

Despite different etiologies, the pathomechanics responsible for MTSS and AT are thought to be similar, with the most commonly cited factors being excessive excursion or velocities of rearfoot eversion.[11,32,48] The structures most commonly implicated in the development of MTSS include the flexor digitorum longus,[6,9] tibialis posterior,[22,43] and soleus muscles,[6,9,34] as well as the deep crural fascia.[9,16] Greater rearfoot eversion, and corresponding lowering of the medial longitudinal arch, would increase the strain within these tissues. This strain could then be transmitted through the fascia resulting in higher forces at the bony insertions.[9] Similarly, greater rearfoot eversion would increase strain within the Achilles tendon, especially in the medial aspect of the tendon which arises primarily from the soleus muscle.[36] **The strain in the Achilles** tendon has been reported as the major factor in determining time to tendon failure when the tendon is subjected to repeated loading cycles[54] and therefore is thought to play a significant role in the development of AT.[15,23] Greater calcaneal eversion will also increase the heterogeneity of strain distribution within the tendon[26], a condition which has been suggested as confounding factor for AT development.[28,29]

Despite these anatomical considerations, there is conflicting evidence in the literature regarding whether high excursion or velocities of eversion are important factors for the development of these two injuries. While several studies have reported greater excursion of eversion in individuals with MTSS[2,8,33,35,38,39,44,50,51,56] others have reported no differences in the amount or velocity of pronation between injured and uninjured individuals.[3,20,37,40] Similarly, while some authors have reported individuals with AT demonstrate greater excursion or velocities of eversion compared to healthy controls, [13,32,42] others have reported no differences between injured and healthy subjects.[18,24]

We hypothesize that it is not the excursion or velocity of eversion that is important for injury development, but rather the duration the rearfoot remains in an everted position throughout stance. During the first half of stance, as the rearfoot everts, the axes of the transverse tarsal, cuneonavicular, and tarsometatarsal joints align allowing the foot to become soft and flexible.[14] During the second half of stance, as the rearfoot supinates, the axes of these joint converge, turning the foot into a rigid lever for use during push off.[14] Therefore, if eversion is prolonged beyond midstance then push off will begin with a soft flexible foot. This configuration may require much greater effort from the intrinsic and extrinsic foot muscles to both stabilize the foot and generate sufficient torque during push off.[21] While the hypothesis of prolonged eversion was first proposed in 1978[21] (then termed prolonged pronation and measured by determining the period of pronation), to date research on MTSS or AT has focused on the excursion, velocities, or time to peak eversion, rather than actual measures of the duration of eversion.

Similar to the debate over rearfoot kinematics, the literature is currently not in agreement regarding whether anatomic alignment, range of motion, arch height, or ground reaction forces are associated with the development of AT or MTSS. Some authors have reported that individuals with both MTSS[8,44,50,56] and AT[32] demonstrate lower arches than controls during quiet standing while other authors have reported no differences in arch height between injured and non-injured subjects.[24,35,40,47] At the ankle, some studies have reported that individuals with MTSS have more plantar flexion range of motion compared to healthy controls[35,49] while other have reported no differences.[3,20] It has also been reported that individuals with AT have both reduced[24] and greater[30] dorsiflexion range of motion than healthy controls. Finally, some authors have reported that ground reaction forces are higher in runners with AT[5,32] while others have reported no differences between injured and healthy runners.[1] Based on these conflicting reports it appears that more work is required to clarify the role of alignment, range of motion, foot structure, and ground reaction forces in regards to these two injuries.

Therefore, the purpose of this retrospective study was to examine whether runners with MTSS or AT demonstrate differences in foot kinematics or measures of lower limb alignment and flexibility compared to healthy controls. We hypothesized that compared to healthy matched controls, individuals with both MTSS and AT would not demonstrate differences in the excursion or velocities of eversion but would demonstrate longer durations of eversion during stance phase. We further hypothesized that there would be no differences in alignment or range of motion between injured runners and controls, and no differences between the two injuries.

METHODS

Subjects

An *a priori* power analysis was conducted using data previously presented in the literature. Based on differences in rearfoot eversion between individuals with MTSS and healthy controls,[33] it was concluded that a minimum of 10 individuals, 5 with MTSS and 5 healthy controls would be required **to** adequately detect differences between these groups (effect size = 0.77, α = 0.05, β = 0.20). Similarly, based on differences in rearfoot eversion between individuals injured with AT and healthy controls[42] it was concluded that a minimum of 24 individuals, 12 with AT and 12 healthy controls, would be required to adequately detect differences between these groups (effect size = 0.67, α = 0.05, β = 0.20).

Based on these estimates, a total of 21 injured individuals, 13 currently symptomatic with AT and 8 currently symptomatic with MTSS, were recruited for this study. Injured participants were specifically diagnosed by and referred from the clinical practices of two collaborating clinicians, one an orthopedic MD, the other a DPT. In addition to diagnosing and referring patients, the clinicians also ruled out any other injuries. For each injured participant, a healthy control was also recruited, thus a total of 42 individuals participated in this study. Controls were matched with injured individuals based on sex, weekly mileage, age, and foot strike pattern (Table 1). Matching for foot strike pattern was initially done using visual analysis and subsequently verified by calculating a strike index for each participant**.** [10] All control participants ran at least 20 miles per week and had not sustained a running related injury within the previous six months. The protocol for this study was approved by the University Institutional Review Board and all participants read and signed an informed consent prior to participating.

Experimental Protocol and Instrumentation

Participants first underwent a clinical exam assessing eleven parameters describing lower limb alignment, mobility, and flexibility (Table 2). Detailed descriptions for performing these measures can be found in Wooden.[53] All range of motion measurements were assessed

Table 1. Participant characteristics for individuals with Achilles tendinopathy (AT), medial tibial stress syndrome (MTSS), and matched controls (CON_AT or CON_MTSS). RFS indicates participants used a rearfoot strike pattern while M/FFS indicates participants used a mid or forefoot strike pattern, as determined by the strike index. **M/F indicates male or female while RFS, M/FFS indicates a rearfoot strike or mid/fore foot strike pattern.**

	Achilles Tendinopathy Participants	
Variable	AT	CON_AT
Sex	9M, 4F	9M, 4F
Weekly mileage (miles)	50.1 (± 15.1)	52.3 (± 14.7)
Foot strike pattern	7 RFS, 6 M/FFS	7 RFS, 6 M/FFS
Age (years)	37.6 (± 15.9)	32.6 (± 12.4)
	Medial Tibial Stress Syndrome Participants	
Variable	MTSS	CON_MTSS
Sex	7M, 1F	7M, 1F
Weekly mileage (miles)	27.5 (± 6.0)	28.8 (± 7.4)
Foot strike pattern	5 RFS, 3 M/FFS	5 RFS, 3 M/FFS
Age (years)	35.3 (± 11.8)	36.4 (± 9.7)

passively with a standard goniometer. Participants were barefoot for all measurements. The exam was performed by one of the two referring clinicians, both of whom have extensive experience assessing and treating injured runners.

Following the clinical exam, thirty nine retro-reflective markers were attached to specific bony landmarks. For the pelvis, thigh, and shank segments a modified Helen Hayes marker set was used. [7,19] For the foot, two markers were placed along the vertical bisection of the calcaneus with one marker on the lateral aspect of the heel counter. Rearfoot markers were placed directly on the skin and visible through holes cut in the shoe.[7] A static trial was collected from which anatomic coordinate systems for the pelvis, thigh, shank, and foot segments were established according to recommendations of the International Society of Biomechanics (ISB).[55] Subjects then completed a running gait analysis where their whole body motion was recorded using a 10-camera motion capture system (Motion Analysis Corp., Santa Rosa, CA) while they ran

Table 2. List of parameters measured during the clinical exam. ROM indicates range of motion.

Clinical Exam Variables	
Arch height index[52]	Hamstring flexibility (°)
Tibia varus relative to ground (°)	Quadriceps flexibility (°)
Passive ankle dorsiflexion ROM (°)	Subtalar inversion ROM (°)
Passive ankle plantar flexion ROM (°)	Subtalar eversion ROM (°)
Prone hip internal rotation ROM (°)	1st metatarsophalangeal joint ROM (°)
Prone hip external rotation ROM (°)	

continuous laps around a short track in the laboratory. [7] Data were collected on each lap over the course of a five-meter straight section. Ground reaction forces were measured with three force plates (AMTI, Watertown, MA) located in series on the straight section of the track. Motion data and ground reaction forces were sampled at 200 Hz and 1000 Hz, respectively. Participants ran continuous laps until a minimum of eight clean trials were recorded. A trial was deemed clean if the foot landed in the middle of a force plate with no visible signs the participant altered their stride to target the force plate. For both AT and MTSS participants their involved limb was used while the matching limb was used for control participants. Participants ran in their own training shoes at self-selected paces approximating their easy training run pace.

Data Analysis

Three dimensional marker trajectories and ground reaction forces were filtered with low pass, fourth order, zero lag Butterworth filters using cutoff frequencies of 8 Hz and 50 Hz, respectively. A fifty Newton threshold in the filtered vertical ground reaction force was used to establish the instants of foot contact and toe off.[10] Foot strike pattern was determined using the strike index.[10] Using the filtered marker trajectories and the anatomic coordinate systems established during the static trial, custom LabView (National Instruments, Austin, TX) software was used to calculate joint angles across stance phase. Angles were calculated using the Cardan rotation sequence recommended by the ISB.[55] From the joint angle data, seven variables describing rearfoot kinematics were calculated (Table 3). In addition, the following kinetic variables were calculated from the filtered ground reaction force data: peak anterior-posterior propulsive forces, propulsive impulses, and peak vertical force. Running speed on each trial was determined using the average anterior velocity of the whole body center of mass, which was recorded across the entire straight five meter data collection section.

Table 3. Kinematic variables extracted for analysis**, definitions and calculation methods.**

Variable (units; abbreviation)	Definition
Period of pronation (% stance)	Time the foot is in a pronated position, expressed as percentage of stance phase. Calculated based on when the rearfoot cross 0° of eversion early in stance to when it re-crosses 0° of eversion late in stance.
Eversion at heel off (°)	Rearfoot eversion at the instant of heel off. Timing of heel off was determined using a local minimum of the inferior heel marker vertical velocity.
Time to heel off (% stance)	Time from foot touchdown until heel off, expressed as a percentage of stance phase.
Peak eversion (°)	Maximum rearfoot eversion during the stance phase.
Eversion excursion (°)	Rearfoot eversion range of motion from touchdown until peak eversion.
Time to peak eversion (% stance)	Time from foot touchdown until peak eversion is reached, expressed as a percentage of stance phase.
Eversion velocity (°/s)	Maximum instantaneous rearfoot eversion velocity between touchdown and peak eversion.

Statistical Analysis

For each dependent variable, an average of all eight trials was used for the statistical analysis. A 2x2 (injury X group) analysis of variance was used to evaluate differences in dependent variables. Injury was a categorical variable with two levels, AT or MTSS. Group was also a categorical variable with two levels: injured or control participant. For the kinematic and kinetic variables running speed was included as a covariate in the analysis. Effect sizes were calculated for all comparisons to aid in the interpretation of results. Effect sizes of 0.1 to 0.25, 0.25 to 0.40 and greater than 0.40 were used to indicate small, medium, and large effects, respectively.[12]

A binary logistic regression was conducted to determine which variables were significant predictors of injured group membership. All clinical exam, kinematic, and kinetic variables which demonstrated significant differences between groups were considered for inclusion, however prior to performing the regression a bivariate correlation was conducted among all combinations of these variables. Where variables demonstrated high correlations ($r > 0.65$), only the variable which was most correlated with the others was retained for the regression analysis. All statistical analyses were performed using Statistical Package for the Social Sciences, version 21 (IBM Corp., Armonk NY).

RESULTS

Clinical Exam Variables

There were no significant group by injury interactions for any of the clinical exam variables (Table 4). For standing tibia varus angle there was a significant main effect of group, with the injured participants demonstrating higher standing tibia varus angles (8.67° ± 1.79°) than the control participants (6.76° ± 1.75°; $p = .002$, ES = 0.58). There was also a significant main effect of group for passive dorsiflexion range of motion, with injured participants demonstrating lower dorsiflexion range of motion (6.14° ± 5.04°) than the control participants (11.19 ° ± 5.1°; $p = .002$, ES = 0.541). None of the other clinical exam variables demonstrated significant main effects of group or main effects of injury.

Table 4. Mean and standard deviations for the clinical exam variables. For hamstring flexibility value in table is distance off from a straight leg. [a] **indicates control participants are significantly different than injured participants at the *p* < .05 level and that this variable was considered for entry into the logistic regression model.**

	AT		MTSS	
Variable	Injured	Control	Injured	Control
Arch height index	0.279 (±0.046)	0.258 (± 0.021)	0.251 (± 0.052)	0.255 (± 0.022)
Standing tibia varus angle (°)	8.69 (±1.88)	6.85 (± 2.04) [a]	8.63 (± 1.77)	6.63 (± 1.31) [a]
Dorsiflexion ROM (°)	7.62 (± 4.36)	11.92 (± 5.34) [a]	3.75 (± 5.42)	10.01 (± 4.89) [a]
Plantar flexion ROM (°)	55.92 (± 6.53)	53.46 (± 9.87)	53.01 (± 7.29)	51.50 (± 9.15)
Hip int. rotation ROM (°)	34.46 (± 6.09)	33.23 (± 8.21)	26.63 (± 6.04)	32.01 (± 11.68)
Hip ext. rotation ROM (°)	25.62 (± 8.08)	25.77 (± 8.52)	29.38 (± 7.76)	30.50 (± 7.80)
Hamstring flexibility (°)	-27.00 (± 14.7)	-20.77 (± 9.97)	-18.50 (± 8.12)	-19.38 (± 6.78)
Quadriceps flexibility (°)	122.62 (± 5.99)	120.08 (± 7.66)	121.01 (± 1.93)	119.38 (± 5.63)
Subtalar inversion (°)	19.62 (± 4.35)	16.15 (± 5.13)	16.50 (± 4.47)	19.25 (± 3.84)
Subtalar eversion (°)	6.69 (± 2.25)	6.46 (± 3.43)	6.63 (± 3.02)	6.25 (± 2.86)
1^{st} MPJ (°)	48.46 (± 9.43)	49.01 (± 18.02)	48.75 (± 7.44)	55.00 (± 12.82)

Kinematic and Kinetic Variables

There were no significant group by injury interactions for any of the kinematic or kinetic variables (Table 5). There was a significant main effect of group for period of pronation, with the injured participants demonstrating longer durations of eversion (86.02 ± 15.65 % stance) than the control participants (59.12 ± 16.5 % stance; $p < .001$, ES = 0.826). The longer duration of eversion is evident in the ensemble average rearfoot eversion/inversion curves for the control and injured participants (Figure 1). There was also a significant main effect of group for eversion at heel off, with the injured participants having a more everted heel at heel off (-6.47° ± 5.58°) than the control participants (1.07° ± 2.26°; $p < .001$, ES = 1.01). None of the other kinematic or kinetic variables demonstrated significant main effects of group or main effects of injury.

Table 5. Mean and standard deviation for the kinematic and kinetic variables. [a] **indicates control participants are significantly different than injured participants at the *p* < .05 level and that this variable was considered for entry into the logistic regression model.**

	AT		MTSS	
Variable	Injured	Control	Injured	Control
Peak eversion (°)	-10.30 (± 6.01)	-10.84 (± 6.33)	-9.05 (± 8.20)	-10.54 (± 7.31)
Eversion excursion (°)	12.43 (± 3.91)	11.59 (± 2.76)	12.05 (± 3.70)	11.84 (± 4.54)
Time to peak eversion (% stance)	30.34 (± 9.01)	23.19 (± 4.57)	23.04 (± 5.60)	21.85 (± 6.23)
Period of pronation (% stance)	86.46 (± 16.35)	60.43 (± 13.75) [a]	85.35 (± 15.50)	57.17 (± 21.15) [a]
Eversion at heel off (°)	-6.58 (± 5.67)	0.34 (± 2.02) [a]	-6.31 (± 6.53)	2.24 (± 2.23) [a]
Time to heel off (% stance)	64.49 (± 10.01)	63.34 (± 6.85)	60.89 (± 4.35)	65.26 (± 7.39)
Eversion velocity (°/s)	281.42 (± 104.91)	351.01 (± 102.86)	299.43 (± 109.90)	360.85 (± 127.50)
Peak propulsive force (BW)	0.31 (± 0.08)	0.29 (± 0.06)	0.25 (± 0.02)	0.28 (± 0.07)
Propulsive impulse (BW*s)	0.21 (± 0.06)	0.22 (± 0.05)	0.24 (± 0.05)	0.26 (± 0.08)
Peak vertical force (BW)	2.71 (± 0.22)	2.62 (± 0.30)	2.39 (± 0.21)	2.53 (± 0.31)

Logistic Regression

The bivariate correlations revealed that period of pronation was highly correlated with eversion at heel off ($r = -0.711$, $p < .001$). Therefore, only period of pronation, tibia varus, and dorsiflexion range of motion were entered into the regression model. The overall model was significant ($\chi^2 = 20.84$, $p < .001$) and was able to correctly classify 81% of the participants into injured and control groups. The model indicated that period of pronation was a significant predictor of group membership with every one percent increase in eversion duration during stance period increasing the odds of being in the injured group by 1.08 (95% confidence interval 1.023 – 1.141, $p = .006$). Neither tibia varus angle ($p = .953$) nor dorsiflexion range of motion ($p = .342$) were significant predictors of group membership.

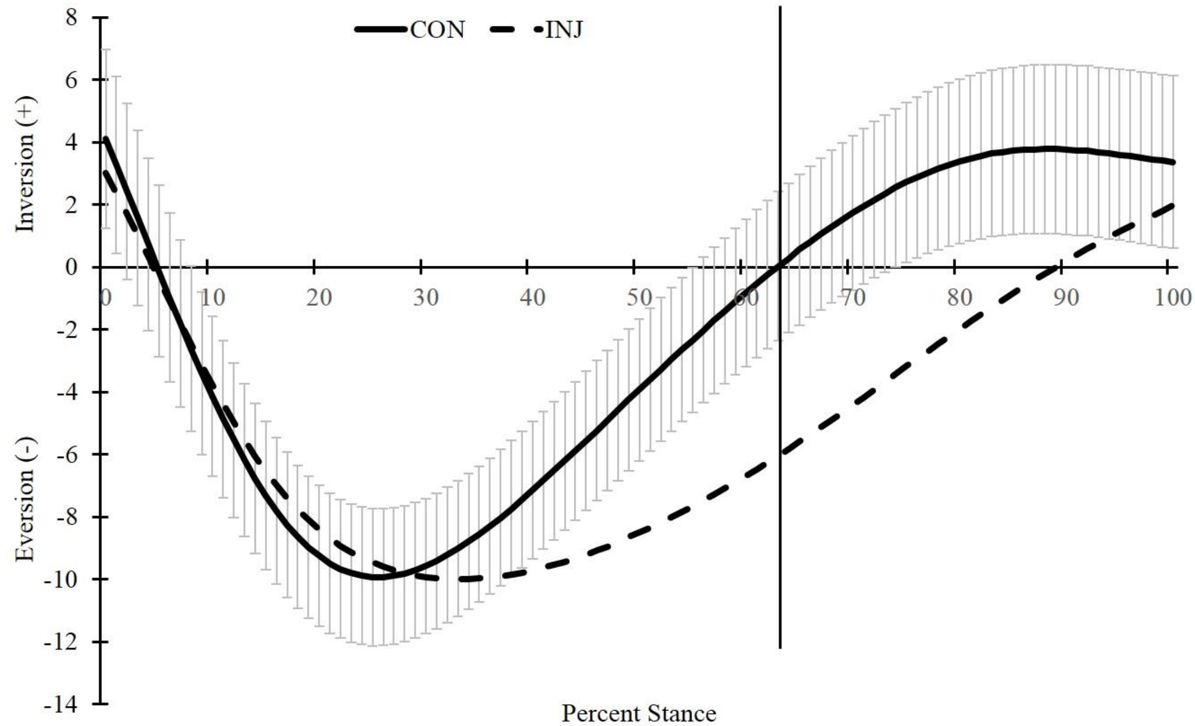

Figure 1. Mean inversion-eversion curves for the pooled injured (INJ) and control (CON) participants. Grey bars represent ± one standard deviation for CON group. Vertical line shows the average percent stance at which heel off occurred.

DISCUSSION

The purpose of this study was to compare measures of alignment and flexibility, rearfoot kinematics, and ground reaction forces between runners with AT and MTSS, and healthy controls. In support of our hypothesis, injured individuals did not demonstrate greater excursion or velocities of rearfoot eversion compared to the healthy controls, but did demonstrate longer durations of eversion, reduced static dorsiflexion range of motion, a more everted rearfoot at heel off, and higher levels of standing tibia varus. This was true for both AT and MTSS groups, suggesting that despite different etiologies, the biomechanical factors associate with these injuries are similar.

The lack of differences in peak propulsive forces, propulsive impulses, or peak vertical ground reaction forces between injured and control participants are consistent with previous studies which have reported no differences in ground reaction force parameters between individuals with AT and healthy controls. [1,32] Additionally, there were no differences in the timing of heel off between injured and control participants. Taken together, these findings indicate that the injured and control participants are pushing off with similar amounts of force and at the same time during stance phase, with the main difference between the two groups being the configuration of the foot while they do so. When heel off occurs the injured group is still everted approximately six degrees while the control group has already achieved an inverted position.

Inversion of the rearfoot is directly linked to locking of the transverse tarsal joints which turns the foot into a rigid lever during push off. [14] Since the injured runners were not achieving this position, it is likely they were pushing off with a less rigid foot. It has been suggested that in this configuration, since the bony structures in the foot are not providing rigidity, then additional effort is required from the extrinsic and intrinsic foot muscles to stabilize the foot.[21] Whether this extra effort is actually present, and its implications for injury, require further investigation. However, if the intrinsic and extrinsic foot muscles are generating higher forces then, depending on how their lengths change, there could be higher strains within the tissues. Higher strains in the Achilles, or transmitted through the crural fascia to the tibia, have been suggested as mechanisms for the development of AT and MTSS, respectively.[26,28,29,45,54] To understand if or how this may be related to injury development future work should further clarify the relationships between foot kinematics and musculotendinous strain.

There is currently no consensus in the literature regarding the relationship between rearfoot kinematics and the development of AT or MTSS. While numerous authors have suggested excessive excursion or velocities of rearfoot eversion are related to the development of these injuries [2,8,13,32,33,35,38,39,42,44,50,51,56] numerous others have reported that these variables do not differ between injured and healthy runners.[3,18,20,24,37,40] The results of the current study support the hypothesis that excursion and velocities of rearfoot eversion may not be important for the development of these injuries, as there were no differences in peak eversion, eversion excursion, time to peak eversion, or eversion velocity between injured and control participants. However, there were differences in the duration of eversion, and this was the only variable which significantly predicted group membership in the logistic regression model.

To date, eversion duration, especially in relation to running injuries, has received little attention in the running biomechanics literature. One study from 1978 (which used the term period of pronation) reported that runners with a history severe of injuries demonstrated longer durations of eversion than a group of runners without an injury history.[4] More recently, a prospective study examining rearfoot kinematics in runners who subsequently sustained an injury reported moderate effect sizes, but non-statistically significant differences in eversion duration between injured and non-injured runners.[25] However, this study had a relatively small sample size and included numerous injuries, not just AT or MTSS. To the authors' knowledge, these two studies, along with the current study, are the only studies to date evaluating the duration of eversion in injured runners. Given the conflicting results, we suggest prospective studies are required to fully understand the relationship between eversion duration and running injuries.

The results of the current study suggest arch height or foot range of motion may not play an important role in the development of AT or MTSS as there were no differences between injured and control participants in arch height index, subtalar joint inversion, eversion range of motion, or 1st metatarsophalangeal joint range of motion. However, our results do suggest that lower extremity alignment and ankle range of motion may play a role in these two injuries. Standing tibia varus angle has been examined in previous work comparing individuals with MTSS to healthy controls,[8,44,50] with the authors suggesting that higher tibia varus angles may be related to the development of MTSS. However, to date, these studies have only shown trends and not shown statistically significant differences between groups. The results of the current study add to this literature and provide additional evidence that higher tibia varus angles may be related to the development of MTSS. However, the relationship between tibia varus angle and rearfoot kinematics requires further clarification as it has been suggested that individuals with a higher tibia varus angle require greater amounts of compensatory pronation simply to get their foot flat on the ground.[21] Greater amounts of compensatory pronation would require higher excursion of rearfoot eversion, a variable which was not different between injured and control participants in the current study.

The reduced static dorsiflexion in injured individuals is in agreement with previous studies which have reported a lack of static ankle dorsiflexion to be predictive of developing both MTSS[33] and AT.[24] Previous authors have suggested that a lack of dorsiflexion may be indicative of a functional equinus and, similar to higher tibia varus angles, may require compensatory pronation simply to get the forefoot flat on the ground.[21] Since compensatory pronation would include additional dorsiflexion and forefoot abduction beyond what is observed in "normal" pronation, it may well increase the forces being applied to the Achilles tendon. This may be one possible reason why studies have reported reduced dorsiflexion as a predictor of sustaining these injuries.

There are a few limitations to the current study that must be considered in interpretation of the results. First, this was a cross sectional retrospective study and participants were already injured when they were evaluated. We did not control for whether injuries were new or recurring or for the relative severity of the injury. Additionally, we did not standardize the method of diagnosis, instead relying on the two experienced clinicians. Thus, it is not possible to state whether the observed differences between injured and control participants were actually responsible for the injuries, a symptom of the injuries, or due to other factors like injury recurrence or severity. Second, our study population was relatively heterogeneous with a mix of two different injuries, males and females, and different foot strike patterns. There were no differences between injury groups, suggesting the biomechanics related to these injuries are similar. However, we did not evaluate whether there were differences between males or females or between runners who utilized a rearfoot verse mid or forefoot strike. Each participant wore their own shoes rather than a standard laboratory shoe. Therefore it is possible that the type of shoe may have influenced the kinematics of the rearfoot. Lastly, this study was done in a motion analysis laboratory not a clinical setting. Many clinical settings lack access to full three dimensional motion capture and therefore it is unlikely they could quantify the period of pronation as was done in the current study. However, period of pronation was highly correlated with eversion at heel off and an everted heel at heel off should be observable using simple video analysis. Thus, the position of the heel at heel off may be a useful tool for identifying prolonged pronators in clinical settings.

One final consideration is the terminology used to describe the foot kinematics observed in the current study. Originally these kinematics were described using the term “prolonged pronation.” [21] However, one could also describe these kinematics as “delayed re-supination,” a term which to the best of the authors knowledge, has not been previously used in the literature. Pronation is largely a passive action due to the relative positioning of the center of pressure and the subtalar joints, and occurs with little to no muscular effort. However, supination is an active movement requiring muscular effort. Thus, while these two terms describe the same kinematics, they may be reflective of different underlying mechanisms, with “prolonged pronation” indicating an alignment or structural issue while “delayed re-supination” suggests a muscular issue. This is perhaps an area for future studies as it is important that the terms used to describe the movement accurately reflect the underlying mechanisms.

In summary, this study examined whether individuals currently symptomatic with either AT or MTSS, two common running injuries typically attributed to excessive excursion or velocities of eversion, instead exhibit prolonged eversion. Compared to healthy controls, injured individuals demonstrated longer durations of eversion, a more everted heel at heel off, higher standing tibia varus angles, and reduced static dorsiflexion range of motion. The lack of differences in either the amount or velocity of pronation between injured and control subjects, and the finding that the best predictor of AT or MTSS group membership was the period of pronation, suggests the problematic mechanics associated with these two injuries occur later in stance phase, during push off, not during the initial loading phase early in stance. **These results** have significant implications for future studies on prevention and rehabilitation of these two common running injuries.

Conflict of Interest

The authors declare they have no conflict of interest.

The results of the study do not constitute endorsement by American Orthopaedic Society for Sports Medicine.

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