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Case report

Footfall patterns of a runner with an Achilles tendon rupture

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Abstract

Purpose: This study aims to compare the load and the length of previously ruptured and healthy Achilles tendon (AT) of a recreational runner who used different footfall patterns on each limb during running.

Methods: A 41-year-old recreational athlete with a ruptured AT participated in this report. Two force plates and a high-speed motion capture system were used to collect ground reaction force and kinematic data in shod and barefoot running conditions. AT length was measured using ultrasonography and an infrared camera system. AT force was estimated as the active plantar flexion moment divided by AT moment arm during stance phase.

Results: The participant used a rearfoot pattern on the affected limb and a forefoot/midfoot pattern on the unaffected limb during shod running, and a forefoot/midfoot pattern during barefoot running. There was no difference between the length of the affected and the unaffected AT. During shod running, the maximal AT force and loading rate were lower in the affected AT versus the unaffected AT. During barefoot running, the affected maximal AT force and loading rate were greater than the unaffected AT.

Conclusion: Footfall patterns can be an adaptation to reduce the loading on a previously injured AT. It appears that runners may consider using a rearfoot footfall pattern during running to reduce the stress on the AT.

Keywords: Achilles tendon; Calcaneus; Footfall patterns; Injury; Running; Tendon length

1. Introduction

Humans are one of the few animals that utilize multiple footfall patterns. Runners may use a forefoot (FF), a midfoot (MF), or a rearfoot (RF) footfall pattern during running.[1,2] Hasegawa et al.[2] reported that approximately 75% of the shod distance runners use an RF pattern and the remaining 25% of the runners use either FF or MF patterns. Only a few studies have reported that some shod runners use different footfall patterns bilaterally.[3,4]

Larson et al.[3] reported some cases where runners exhibited a bilateral difference in footfall patterns with an RF pattern mostly on non-dominant foot and an FF pattern on dominant foot. They stated that it is unclear whether these combined landing patterns were a single uncommon footfall pattern sequence or simply a gait asymmetry. Williams et al.[4] described an elite female runner with combined footfall pattern and speculated that this asymmetry was related to a previous groin injury. The current study is unique in trying to explain the cause of the unusual utilization of the combination of RF and FF footfall patterns. Some authors assume that MF and FF are natural types of footfall pattern that reduce running related injuries[5,6] and so the change to an FF pattern may be the result of escaping injury to one or the other limbs.

Recently, a runner who used different footfall patterns with each limb during shod running appeared in our laboratory during a research study of recreational runners with a history of Achilles tendon (AT) rupture. There is previous evidence of altered ankle kinematics during stance phase of 2 runners with an elongated AT.[7,8] Furthermore, AT elongation is a common problem for people with history of rupture.[9] AT rupture is a devastating injury that causes a functional deficit of the plantar flexors.[10] In spite of this, humans after AT rupture are still active as recreational athletes. However, running may not be without consequences if the previous musculo-skeletal system injury is associated with a higher incidence of injury among runners.[11]

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The second most common running related injury is Achilles tendinopathy whose incidence is estimated at 9.1%–10.9% of all runners.[12] To prevent or even “cure” running injuries, it has been suggested that runners should use either an FF or an MF footfall pattern.[5,6] However, Gruber et al.[13] reported that an FF footfall pattern is associated with higher AT forces compared to the RF pattern. Higher AT forces during running may indicate a greater risk of AT injuries.[14]

Therefore, the purpose of this study was to compare AT loading and AT length of the affected (previous AT rupture) and the unaffected (no injury) AT of a recreational runner who used a combined footfall pattern (i.e., FF on unaffected limb and RF on the affected limb). We hypothesized that the affected AT would appear elongated compared to the unaffected AT which could subsequently affect the ankle kinematics while running.[7,8] In addition, we expected a less loading on the affected AT compared to the unaffected AT. This study offers a unique opportunity to understand the preventive strategies and adaptations of the neuro-muscular system against overloading the weakened structures of the human body.

2. Case report

2.1. Participant

A 41-year-old recreational athlete and professional fireman sustained AT rupture on the left limb when he suddenly changed direction during running. The AT was sutured by mini-invasive technique on the day of the injury. Treatment of the subsequent inflammation required ablation of the proximal part of the calcaneus. From an ultrasonograph examination, a noticeable defect of the calcaneus and insertion of the affected AT was apparent (Fig. 1). Further treatment resulted in casting the knee and ankle for 6 weeks and followed by 4 months of rehabilitation. Four years later, this individual participated in a research study of running biomechanics of participants with a history of AT rupture. This individual reported that he used an FF footfall pattern when running before the AT injury. The procedure was approved by the University of Ostrava Ethics Committee and the written informed consent was obtained from the participant.

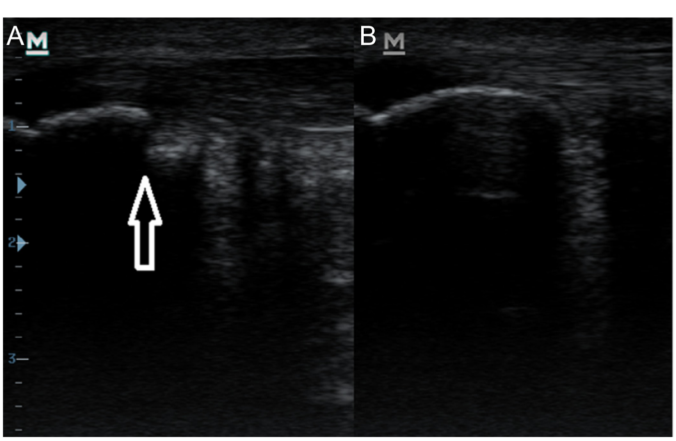

Fig. 1. Ultrasonography of the (A) affected and (B) unaffected insertion of the Achilles tendon on calcaneus.

At the time of the research study in which the subject initially completed, the participant’s body mass was 86.5 kg, height 1.73 m, and body fat 23% of the total body weight. He reported a fifth level of physical activity (i.e., medium intensity exercise at least 3 times per week).[15] The maximum moment of force during the isometric contraction of dorsal and plantar flexors was measured using a force plate (Fitronic; FitroForce, Bratislava, Slovakia) with the individual’s lower extremity positioned at 90° of flexion at the ankle, knee, and hip.[16]

The results of the analysis indicated a greater dorsiflexor moment on the repaired AT limb versus the unaffected AT (difference 11 N·m, effect size (ES) > 0.8) and a weaker plantar flexor moment on the affected limb (difference 41 N·m, ES > 0.8) compared to the repaired AT limb. The runner reported no pain or restrictions in activity shown by the Foot and Ankle Outcome Score (FAOS).[17] However the Achilles tendon Total Rupture Score (ATRS) was rated at 44, causing the runner to feel limited during running.[18]

2.2. Instrumentation, protocol, and statistics

Two force plates (Kistler, 9286AA and 9281CA; Kistler Instrumente AG, Winterthur, Switzerland) were used to collect ground reaction force data. The force platforms were placed in a 17 m long runway and were situated flush with the floor. Data were sampled at a frequency of 1200 Hz. Retro-reflective markers were placed on the subject prior to data collection according to the protocol suggested by Hamill and colleagues.[19] Calibration markers were placed bilaterally on the lateral and medial malleoli, the medial and lateral femoral condyles, the greater trochanter, and on the shoe/foot over the first and fifth metatarsal heads. Tracking markers were securely positioned to define the pelvis (iliac crest and posterior superior iliac spine, anterior superior iliac spine), the thighs and shanks (4 lightweight rigid plates holding a quaternion of markers), and the shoe/foot (a triad of markers on the heel over the calcaneus). Kinematics of the foot, leg, thigh, and pelvis were recorded at a frequency of 240 Hz using a motion capture system (Oqus 100; Qualisys AB, Göteborg, Sweden).

The participant completed a 5 min warm-up prior to data collection. Subsequently, he completed 5 acceptable trials over the force platforms at a speed of 3.2 m/s (±5%) in each of 2 conditions: (1) running shod (Mizuno Crusader; Mizuno Corp., Osaka, Japan) and (2) running barefoot. The barefoot condition was included to determine that the individual was capable of running with an FF pattern. The difference in the dependent variables was evaluated using ES, which was calculated and interpreted as trivial with ES $\leq$ 0.2, small with ES >0.2 and $\leq$0.50, medium with ES >0.5 and $\leq$0.80, and large with ES > 0.8.[20]

2.3. Footfall pattern

This individual clearly used an RF pattern on affected and an FF pattern on unaffected foot when shod (Figs. 2A and 3 and Table 1). During barefoot running, he used only an FF footfall pattern (Fig. 2E). However, during barefoot running, the ankle plantar flexion angle on the unaffected lower extremity was

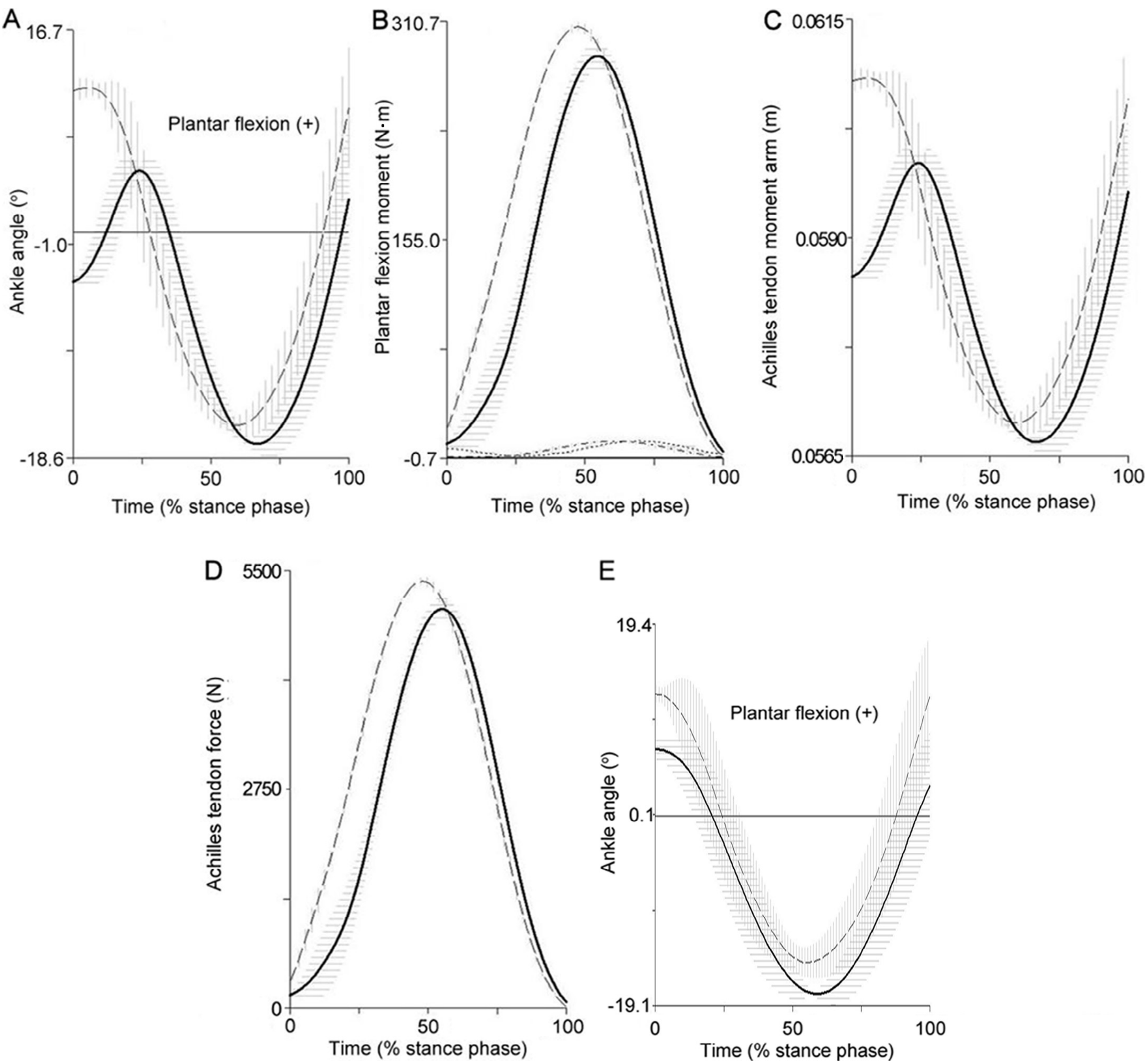

Fig. 2. Comparison of the affected (solid curve) and unaffected (dashed curve) ankle joint kinematics and kinetics during stance phase of shod running (A–D) and barefoot running (E) (n = 5 trials, mean ± SD). (A, E) The angle in the ankle joint; (B) Active moment of plantar flexors and passive ankle moments on the unaffected (dot dash) and the affected (with dots); (C) Achilles tendon moment arm; and (D) Achilles tendon force.

different from that on the affected limb (Table 1). While still using an FF/MF pattern, the plantar flexion angle on the affected limb was much reduced and may indicate a transition to a less FF and more MF pattern.

2.4. AT length, force, and loading rate

AT length was measured by a non-invasive method that combined both ultrasonography and an infrared camera system.[21] AT length was defined as the distance between the gastrocnemius musculotendinous junction and the calcaneal osteotendinous junction.[7] There was no difference between the length of the affected and the unaffected AT (Table 2).

Visual 3D (C-motion, Rockville, MD, USA) was used to determine the AT force. To estimate AT moment arm (Fig. 2C), we used a regression equation.[22] An estimate of the passive ankle moment was subtracted from the net ankle moment to determine the active plantar flexion moment (Fig. 2B).[23] The AT force was estimated as the active plantar flexion moment divided by AT moment arm during the stance phase (Fig. 2D). During shod running, the maximal AT force was 348 N lower in the affected AT versus the unaffected AT. The AT loading rate

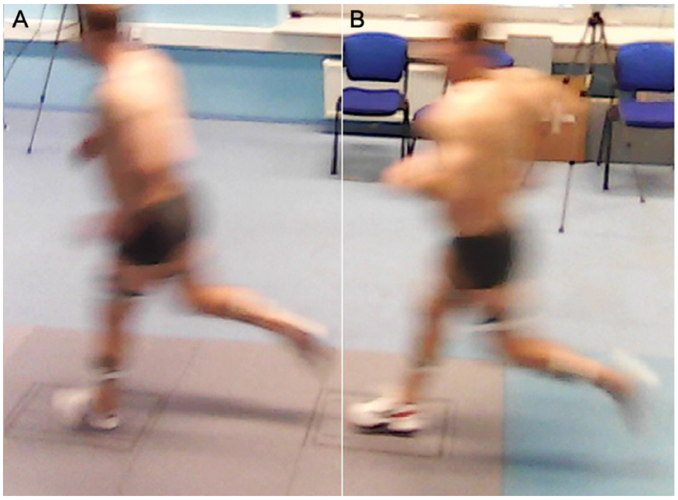

Fig. 3. Footfall patterns of a shod runner with an Achilles tendon rupture during the instant of initial contact within a single running cycle. Note (A) the rearfoot footfall pattern on the affected foot and (B) the forefoot/midfoot footfall pattern on the unaffected foot.

Table 1
Comparison of ankle angle during initial contact on the affected and unaffected lower extremity while running in shoes (SH) and barefoot (BF).

Variable	Affected	Unaffected	Difference (ES)
Ankle angle during SH (°)	−4.10 ± 0.46	11.66 ± 0.82	−15.76 (34.1)[a]
Ankle angle during BF (°)	6.77 ± 0.94	12.30 ± 0.91	−5.53 (6.1)[a]

Note: Negative ankle angle represents dorsiflexion, positive ankle angle represents plantarflexion.
[a] Practical significance according to Cohen.[20]
Abbreviation: ES = effect size.

Table 2
Comparison of AT length and loading on the affected and unaffected lower extremity while running in shoes.

Variable	Affected	Unaffected	Difference (ES)
AT length (m)	0.232 ± 0.003	0.232 ± 0.001	0 (0)
AT maximal force (N)	5017 ± 152	5365 ± 50	−348 (6.9)[a]
AT loading rate (N/s)	37,600 ± 1637	45,446 ± 2141	−7846 (3.6)[a]

[a] Practical significance according to Cohen.[20]
Abbreviations: AT = Achilles tendon; ES = effect size.

followed a similar trend with a difference of 7846 N/s (Table 2, Fig. 2D). During barefoot running, the affected maximal AT force was 221 N greater than unaffected maximal AT force. Again there was a similar trend for the AT loading rate with a difference of 1651 N/s between the affected and the unaffected AT loading rates.

3. Discussion

In this case report, we described a unique runner who used different footfall patterns on the AT ruptured limb and the unaffected AT in a single gait cycle during shod running. We hypothesized that the affected AT would be elongated which subsequently could affect the kinematics of the ankle joint movement during stance phase of running. Contrary to our hypothesis, AT length did not differ between limbs. Further, we hypothesized that the affected AT may have altered loading during running. The individual in this report showed an asymmetry during shod running using an RF pattern on the affected AT and an FF/MF pattern on the unaffected AT. He showed an AT loading asymmetry with a greater AT load on the FF footfall pattern or unaffected side. In contrast, during barefoot running, when this individual used only FF/MF pattern, loading of affected AT was greater than on the unaffected side.

Repetitive tendon loading, such as that experienced during distance running, may initiate production of prostaglandin E2 which can result in degenerative changes within the tendon.[24,25] Sinclair[14] advocated that barefoot running (i.e., with an FF pattern) may not be appropriate for runners who are predisposed to AT pathology. He showed increased AT loading during barefoot running compared to shod running in healthy individuals. Gruber and associates[13] reported that there was decreased loading of the AT in the loading phase during an RF pattern. On the other hand, the AT was loaded throughout the support phase in an MF/FF footfall pattern. Thus, an RF footfall pattern on the affected side (i.e., the previously injured AT) during shod running could be protective mechanism against chronic injuries of the AT with history of rupture.

Alternatively, based on the isometric measurements, there was a weaker plantar flexor moment on the affected limb indicating that the asymmetric loading may be due to differences in the capability of the muscles rather than the use of RF loading as a "protective mechanism". However, the runner used the FF/MF footfall pattern when barefoot (Fig. 2E). This provides support for the fact that the participant had sufficient plantar flexion strength for FF/MF running but chose not to do during shod running.

Currently, the individual from this study does not feel any pain but he feels limited during running. Despite the subjective difficulties, 4 years after the AT surgery, he performs physical activity of medium intensity 3 times a week and carries on his physically demanding profession as a firefighter. The participant self-reported the use of an FF/MF footfall pattern before measurement. We identified a mixed footfall pattern after the measurement of shod running. The low number of FF/MF distance runners in the population[2] could be an explanation for the rare occurrence of switching the footfall pattern from FF/MF to RF on the affected lower extremity. Running with the FF/MF footfall pattern on both lower extremities when barefoot (Fig. 2E) provides support for our hypothesis of the FF/MF footfall pattern bilaterally before injury.

In conclusion, we described a unique case of a physically active individual who uses different footfall patterns bilaterally when running. This asymmetry in footfall patterns may be a result of the AT loading on the leg with a history of AT rupture. Different footfall patterns could affect the AT forces[13] and may be an adaptation to the weakening of osteotendinous junction. However, the asymmetry was not related to AT elongation. These results suggest that an RF footfall pattern may be an adaptation to reduce the loading on the AT that was previously injured. This extreme case of combined footfall pattern can contribute to an understanding of the reasons for the strategy of footfall pattern in general.

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Authors' contributions

DJ carried out the measurement, participated in the biomechanical analysis and manuscript drafting, performed the statistical analysis, conceived of the study and participated in its design; JU, RF, and DZ carried out the measurement; JH participated in the biomechanical analysis, conceived of the study, participated in its design and coordination, and helped draft the manuscript. All authors have read and approved the final version of the manuscript, and agree with the order of presentation of the authors.

Competing interests

The authors declare that they have no competing interests.

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