Original Article

The relationship between movement of the shank while running and foot alignment factors that lead to the onset of Achilles peritendinitis

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Abstract. [Purpose] To clarify the relationship between movement of the shank relative to the global reference frame (shank angle) while running, and foot alignment factors that lead to the onset of Achilles peritendinitis. [Participants and Methods] This study included 54 healthy male participants. Running at a constant speed was measured by three-dimensional motion analysis. The shank angle at the time of the first peak of vertical ground reaction force and maximum ankle dorsiflexion were analyzed. The magnitude of ankle plantarflexion, inversion, and adduction angle in the propulsive phase as well as static foot alignment (navicular index, and range of ankle dorsiflexion angle) were measured. The relationships between shank angle features and these parameters were investigated. [Results] Outward inclination of the shank occurred at the time of the first peak of vertical ground reaction force and maximum ankle dorsiflexion, with this increase in movement correlating with parameters that increased the risk of Achilles peritendinitis. [Conclusion] These findings suggest that evaluation of the shank angle on the frontal plane while running may be used to estimate the onset of Achilles peritendinitis in clinical practice.

Key words: Running, Shank, Motion analysis

INTRODUCTION

Running is a relatively simple, healthy and popular recreational fitness activity. However, the repetitive nature of running can lead to overuse injuries in both recreational and competitive runners. Achilles peritendinitis is one of the most common running injuries, representing 8–15% of all injuries in recreational runners and 24% of those in competitive runners1–3). Therefore, appropriate clinical evaluation is required for prevention of Achilles peritendinitis.

Achilles peritendinitis is a multifactorial process, influenced by both extrinsic and intrinsic risk factors, especially by lower limb alignment while running3–4). Previous studies have focused on the kinematics and kinetics of participants who have developed Achilles peritendinitis while running. For example, ankle dorsiflexion velocity and eversion velocity are lower5–7), while ankle eversion and knee internal rotation ranges of motion are higher5, 8); in participants with Achilles peritendinitis. A longitudinal study reported that participants who developed Achilles peritendinitis had lateral force distribution of foot pressure during the propulsive phase of stance9). This, in turn, led to excessive ankle supination (plantarflexion/inversion/adduction)9). In this study, the phase until the reaction force switched to the forward component of the force was defined as the braking phase and the phase of the forward component of the force was defined as the propulsive phase as in previous studies10).

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Risk factors for onset of Achilles peritendinitis have been reported to include the influence of foot static alignment. Flat foot may lead to excessive ankle dorsiflexion, resulting in the onset of Achilles peritendinitis. Excessive extension stress of the triceps muscle was reported due to restricted ankle dorsiflexion, to have resulted in the onset of Achilles peritendinitis. Longitudinal studies have also analyzed the relationship between the onset of Achilles peritendinitis and these foot static alignments, suggesting that foot static alignment with flat foot or restrictive ankle dorsiflexion were features leading to the onset of Achilles peritendinitis.

For these reasons, evaluation of both foot static alignment and ankle movement while running may be used to estimate the onset of Achilles peritendinitis. However, ankle movement while running is small, making visual inspection difficult in clinical practice. Ankle movement can be defined as movement of the foot relative to the shank. The Achilles tendon is a combination of the tendons of the soleus and gastrocnemius muscles, inserted approximately halfway down the calcaneus. Thus, assessing movements of the ankle joint may be determined not only by the movement of the foot relative to the shank but by the shank relative to the global reference frame (shank angle). The shank is a large segment of the body, allowing easier visualization while running compared to visualization of ankle movement.

The present study was designed to clarify the relationship between shank angle while running and foot alignment factors that lead to the onset of Achilles peritendinitis. In this study, we decided to explore the possibility of these relationships in people with no Achilles peritendinitis. The hypothesis was that excessive outward inclination of the shank would show the same results as foot alignment factors that lead to the onset of Achilles peritendinitis, because excessive outward inclination of the shank in the frontal plane causes twisting movement in the Achilles tendon as well as excessive ankle pronation.

PARTICIPANTS AND METHODS

The study participants included 54 healthy adult males with no previous orthopedic ailment within the past 6 months. They had a mean (± standard deviation) age of 21.8 (± 1.1) years, a mean height of 170.2 (± 1.4) cm and a mean body mass of 62.1 (± 1.1) kg. All participants provided written informed consent, in accordance with the Declaration of Helsinki, and the study protocol was approved by the ethics committee of the International University of Health and Welfare (No.13-Ig-74).

Kinematic data was obtained using a 3D motion analysis system (Vicon Nexus, 9 camera). Synchronized kinetic data was captured using two conventional in ground reaction force plates (AMTI). A force plate mounted in the center of the runway recorded ground reaction forces of the right stance phase. Kinematic data were sampled at 200 Hz and force data at 1,000 Hz. Sixteen retroreflective markers, each 14 mm in diameter, were placed bilaterally on the lower body. Markers were placed bilaterally on segments of the anterior inferior iliac spine, posterior inferior iliac spine, lateral thigh, lateral knee, lateral shank, lateral malleolus, calcaneal tuber and head of the second metatarsal bone.

Participants ran three laps along a straight pathway in the laboratory at a constant speed of about 3 m/s. In this study, we visually confirmed that all participants ran using a rearfoot strike pattern. These measurements were repeated three times.

The 3D coordinates of each marker were reconstructed using VICOM Nexus software. Data obtained with the 3D motion analysis system were processed using Nexus 1.7.1 software (VICON). The 3D coordinates and force plate data were low-pass filtered at 10 Hz and 50 Hz, respectively. The Plug-In-Gait model on Nexus software was used to calculate right ankle joint angle. The right shank angle was calculated by defining the local coordinate system for each body segment using the programming language Body Builder. Shank segment was defined by three points, the lateral knee, lateral shank and the lateral malleolus. Using these local coordinate systems, movement of the shank relative to the global reference frame was calculated using Euler angles.

The features of the shank angle at the time of the first peak of vertical GRF and maximum ankle dorsiflexion while running were analyzed, because previous studies reported that the onset of Achilles peritendinitis was estimated at these instants. The maximum ankle dorsiflexion was defined as the maximum ankle dorsiflexion angle during stance phase.

Foot static alignment, foot deformity and the range of ankle dorsiflexion angle were documented. Foot deformity was determined by the Navicular index, and the range of ankle dorsiflexion angle was measured. The relationships of shank angle with ankle supination angle in propulsive phase, the degree of flat foot and range of ankle dorsiflexion angle were investigated. Ankle supination angle in propulsive phase was determined by measuring the magnitude of plantarflexion, inversion and adduction angles.

All statistical analyses were performed using SPSS Statistics 22 software (IBM). Pearson correlation analysis was performed to investigate the relationships between shank angle at the time of the first peak of vertical GRF and maximum ankle dorsiflexion and the magnitude of ankle plantarflexion, inversion and adduction angles in propulsive phase; Navicular index; and ankle dorsiflexion range. P values <0.05 were considered statistically significant.

RESULTS

Table 1 shows the forward/backward inclinations of the shank in the sagittal plane and the outward/inward inclinations of the shank in the frontal plane at the time of the first peak of vertical GRF and at maximum ankle dorsiflexion in all participants. All participants showed backward and outward inclination of the shank at the time of the first peak of vertical GRF and forward and outward inclination of the shank at maximum ankle dorsiflexion.
Table 2. Relationship between movement of the shank and the magnitude of angle of the foot (r values)

| Forward/backward inclination of the shank | Outward inclination of the shank |
|------------------------------------------|---------------------------------|
| Magnitude of ankle plantarflexion angle in propulsive phase | 0.26 | 0.24 | 0.06 | 0.19 |
| Magnitude of ankle inversion angle in propulsive phase | −0.01 | −0.15 | −0.23 | −0.23 |
| Magnitude of ankle adduction angle in propulsive phase | −0.13 | 0.19 | 0.36* | 0.43* |

N=54.
* p<0.05.

Table 3. Relationship between the movement of the shank and the static foot alignment (r values)

| Forward/backward inclination of the shank | Outward inclination of the shank |
|------------------------------------------|---------------------------------|
| Navicular index | 0.16 | 0.17 | 0.31* | 0.13 |
| Range of ankle dorsiflexion angle (°) | 0.1 | −0.11 | −0.44* | −0.44* |

N=54.
* p<0.05.

Table 2 shows the relationships between the movement of the shank and the magnitude of plantarflexion, inversion and adduction angles of the foot in propulsive phase (r values).

We observed a weak correlation between the outward inclination of the shank at the time of the first peak of vertical GRF and the magnitude of ankle adduction angle in propulsive phase (r=0.36, p<0.05) and a moderate correlation between the outward inclination of the shank at maximum ankle dorsiflexion and the magnitude of ankle adduction angle in propulsive phase (r=0.43, p<0.05). No other correlations were statistically significant.

Table 3 shows the relationships between the forward/backward inclination and the outward inclination, respectively, of the shank and static foot alignment assessed by the Navicular index, with the range of ankle dorsiflexion angle. We observed a weak positive correlation between the outward inclination of the shank at the time of the first peak of vertical GRF and the Navicular index (r=0.31, p<0.05), a moderate negative correlation between the outward inclination of the shank at the time of the first peak of vertical GRF and the range of ankle dorsiflexion angle (r=−0.44, p<0.05), and a moderate negative correlation between the outward inclination of the shank at maximum ankle dorsiflexion and the range of ankle dorsiflexion angle (r=−0.44, p<0.05). No other statistically significant correlations were observed.

**DISCUSSION**

This study showed that the outward inclinations of the shank at the time of the first peak of vertical GRF and maximum ankle dorsiflexion were positively correlated with the magnitude of adduction angle of the foot in propulsive phase. Because outward inclination of the shank indicates movement on the frontal plane, outward inclination of the shank relative to the global reference frame would show the same view as eversion of the foot. Therefore, an increase in outward inclination of shank is associated with an increase of eversion of the foot. Excessive ankle supination in propulsive phase is thought to compensate for the movement of plantarflexion caused by the reduction in foot rigidity, which is due to the excessive eversion position of the ankle in the braking phase\(^{19}\). Therefore, excessive ankle eversion in the braking phase is likely related to
the excessive ankle supination in the propulsive phase, as well as to the increase in the magnitude of ankle adduction angle included in ankle supination. Thus, increased outward inclinations of the shank at the time of the first peak of vertical GRF and maximum ankle dorsiflexion were associated with increased magnitude of ankle adduction angle in the propulsive phase.

This study found that outward inclination of the shank at the time of the first peak of vertical GRF was positively correlated with the Navicular index, whereas outward inclination of the shank at the time of the first peak of vertical GRF and maximum ankle dorsiflexion were negatively correlated with the range of ankle dorsiflexion angle. Navicular index can indicate high and low arched feet (18). In general, the foot functions as a shock absorber at the time of the first peak of vertical GRF, changing from ankle inversion to ankle eversion (15). Excessive ankle eversion may be due to falling of the talus into the inside when the arch of the foot is lowered (5, 20, 21). Thus, an increase in Navicular index was associated with excessive ankle eversion at initial contact. Restrictive ankle dorsiflexion can give rise to compensatory ankle eversion while running (49). Because all participants in this study had a rearfoot strike pattern, those with restrictive ankle dorsiflexion may have had compensatory movements of ankle eversion at the time of the first peak of vertical GRF and maximum ankle dorsiflexion.

These findings indicate relationships among increased outward inclination of the shank at the time of the first peak of vertical GRF, increased Navicular index value and restrictive ankle dorsiflexion, as well as a relationship between increased outward inclination of the shank at maximum ankle dorsiflexion and restrictive ankle dorsiflexion.

For these reasons, the hypothesis in this study was supported and it was suggested that increase in the outward inclination of the shank would be associated with foot alignment factors that lead to the onset of Achilles peritendinitis. In clinical practice, evaluation of shank angle on the frontal plane while running may be used to estimate the onset of Achilles peritendinitis. This study had several limitations. First, this study showed that outward inclination of the shank at the time of the first peak of vertical GRF and at maximum ankle dorsiflexion contact correlated positively with the magnitude of ankle adduction in the propulsive phase and negatively with the range of ankle dorsiflexion angle. Furthermore, outward inclination of the shank at maximum dorsiflexion correlated positively with Navicular index. However, these correlation coefficients were not strong correlation, limiting the interpretation of these results. Second, although foot touchdown while running can include rearfoot contact and forefoot contact (22), all participants in this study showed rearfoot contact while running. Therefore, the results of this study are limited to features of running motion involving rearfoot contact.

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None.

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