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Competitive Female Runners With a History of Iliotibial Band Syndrome Demonstrate Atypical Hip and Knee Kinematics

Iliotibial band syndrome (ITBS) is the second leading cause of knee pain in runners and the most common cause of lateral knee pain.[21,26] Anecdotally, this syndrome has been associated with repetitive flexion and extension on a loaded knee, in combination with a tight iliotibial band.[1,16,21-23] Orchard et al[23] suggested that frictional forces between the iliotibial band and the lateral femoral condyle are greatest at 20° to 30° of knee flexion, which occur during the first half of the stance phase of running. However, despite this well-accepted sagittal-plane theory,[1,21,23] no differences have been found in the few biomechanical investigations that have examined knee flexion/extension patterns in runners who had ITBS compared to healthy controls.[16,22]

• **STUDY DESIGN:** Cross-sectional experimental laboratory study.

• **OBJECTIVE:** To examine differences in running mechanics between runners who had previously sustained iliotibial band syndrome (ITBS) and runners with no knee-related running injuries.

• **BACKGROUND:** ITBS is the second leading cause of knee pain in runners and the most common cause of lateral knee pain. Despite its prevalence, few biomechanical studies have been conducted to better understand its aetiology. Because the iliotibial band has both femoral and tibial attachments, it is possible that atypical hip and foot mechanics could result in the development of ITBS.

• **METHODS:** The running mechanics of 35 females who had previously sustained ITBS were compared to 35 healthy age-matched and running distance-matched healthy females. Comparisons of hip, knee, and ankle 3-dimensional kinematics and internal moments during the stance phase of running gait were measured.

• **RESULTS:** The ITBS group exhibited significantly greater peak rearfoot invertor moment, peak knee internal rotation angle, and peak hip adduction angle compared to controls. No significant differences in peak rearfoot eversion angle, peak knee flexion angle, peak knee external rotator moment, or peak hip abductor moments were observed between groups.

• **CONCLUSION:** Females with a previous history of ITBS demonstrate a kinematic profile that is suggestive of increased stress on the iliotibial band. These results were generally similar to those reported for a prospective study conducted within the same laboratory environment. *J Orthop Sports Phys Ther 2010;40(2):52-58. doi:10.2519/jospt.2010.3028*

• **KEY WORDS:** *ankle, biomechanics, foot, running*

It is possible that motions in other planes, or at other joints, may contribute to ITBS. The primary functions of the iliotibial band are to serve as a lateral hip and knee stabilizer and to resist hip adduction and knee internal rotation.[8,17] The iliotibial band originates from the fibers of the gluteus maximus, gluteus medius, and tensor fascia latae muscles, and attaches proximal to the knee joint into the lateral femoral condyle and distal to the knee joint into the infracondylar tubercle of the tibia.[1,17] As a result of the femoral and tibial attachments, it is possible that atypical hip and foot mechanics, which both influence the knee, could play a role in the development of ITBS.

Distally, it has been suggested that excessive rearfoot frontal-plane motion influences knee mechanics.[3,9,14,28] During the first half of the stance phase, the calcaneus everts and the head of the talus internally rotates.[11,13] Consequently, the tibia internally rotates with the talus due to the tight articulation of the ankle joint mortise.[11,13] Because the iliotibial band attaches to the lateral condyle of the tibia, it is postulated that excessive

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TABLE 1 Group Demographics*

Variables of Interest	Iliotibial Band Syndrome	Control
Age (y)	35.47 ± 10.35	31.23 ± 11.05
Mass (kg)	58.62 ± 3.97	61.30 ± 6.97
Height (m)	1.65 ± 0.06	1.67 ± 0.07
Monthly running distance (km)	123.82 ± 62.64	119.27 ± 52.02

* *Values are mean ± SD.*

rearfoot eversion, resulting in greater tibial internal rotation, could increase the strain in the iliotibial band. Several studies have cited increased rearfoot eversion as a contributing factor to lower extremity injuries.[15,24,28] Recently, Miller et al[16] reported that at the end of an exhaustive run, runners with ITBS demonstrated a greater rearfoot inversion angle at heel strike compared to controls, which they hypothesized contributed to a greater peak knee (tibial) internal rotation velocity and thus torsional strain to the iliotibial band. In contrast, Messier et al[15] reported that runners with a history of ITBS exhibited no difference in rearfoot mechanics while running, compared to healthy individuals. However, Messier et al[15] did not utilize an exhaustive run protocol, which may account for the different findings between these 2 studies. Thus, further investigation regarding the role of atypical foot mechanics and the development of ITBS is necessary.

Proximally, abnormal hip mechanics have also been suggested to play a role in development of ITBS.[4,7] The gluteus medius muscle is the primary abductor of the hip joint,[17] and weakness of this muscle may lead to an increase in hip adduction angle, thereby potentially increasing the strain on the iliotibial band.[11,12,25] Although running kinematics was not addressed, Fredrickson et al[8] reported that runners with ITBS had significantly reduced hip abductor muscle strength in the affected limb compared to the unaffected limb, as well as compared to healthy controls. In addition, Niemeth et al[19] investigated a group of runners with a variety of musculoskeletal injuries, including ITBS. These authors also indicated that the injured runners demonstrated significantly reduced hip abductor muscle strength compared to the noninjured limb and compared to a group of noninjured runners. Thus, hip abductor weakness, possibly leading to increase hip adduction during the stance phase of running, may be related to the development of ITBS. However, few studies have investigated whether atypical hip mechanics may play a role in the aetiology of ITBS.

A recent prospective study by Noehren et al[22] examined proximal (hip), distal (rearfoot), and local (knee) mechanics in the development of ITBS. These authors concluded that runners who developed ITBS exhibited increased hip adduction and knee internal rotation angles compared to those runners who remained uninjured. No differences were found in rearfoot eversion or knee flexion. In addition, these authors reported that rearfoot, knee, and hip moments were all similar between groups. Although prospective studies are more robust in design and can provide information concerning cause and effect, we sought to confirm the results of our previously published prospective study with a retrospective analysis. Apart from confirming the robustness of our previous results, a follow-up retrospective study of individuals with a history of ITBS would shed insight as to whether runners alter their mechanics once the injury has resolved.

The purpose of this retrospective study was to examine differences in hip, knee, and ankle joint running biomechanics between female runners who had previously sustained ITBS compared to healthy controls. Based on the current literature and the prospective study by Noehren et al,[22] it was hypothesized that female runners who had previously sustained ITBS would exhibit greater peak rearfoot eversion, knee internal rotation, knee flexion, and hip adduction angles during stance. In addition, greater rearfoot invertor, knee external rotator, and hip abductor internal moments were expected.

METHODS

Subjects

A PRIORI SAMPLE SIZE POWER ANALYsis (β =.20; α =.05) was conducted using variability obtained from the kinematic variables of interest from previous studies.[5,22] Based on this analysis, a minimum of 14 subjects per group were needed to adequately power the study. The subjects involved in this study (n = 70) were part of a larger, ongoing prospective investigation of female runners (n = 400; ages 18-45 years, minimum running distance of 30 km/wk, and free of any obvious lower extremity malalignments or injuries at the time of data collection). As part of the larger study, all previous lower extremity injuries for all participants were recorded. Thirty-five females, who had a past history of ITBS documented by a medical professional (ie, physical therapist, medical doctor, athletic trainer), were identified. Thirty-five females, matched for age and running distance, with no previous knee-related musculoskeletal injuries, were then chosen for the control group. No significant differences in group demographics were observed (**TABLE 1**). Prior to participation, each subject signed a consent form approved by the University of Delaware Human Subjects Compliance Committee.

Procedures

Retroreflective markers for tracking 3-D

FIGURE 1. Retroreflective marker placement on the tested lower extremity.

movement were attached to the thigh, shank, pelvis, and rearfoot (**FIGURE 1**). Additional anatomical markers were placed over the bilateral greater trochanters, medial and lateral femoral condyle, medial and lateral malleoli, and the heads of the first and fifth metatarsals. These markers were used to define the anatomical coordinate systems and calculate the inertial parameters for each body segment. After data for a static standing calibration were collected, the anatomical markers were removed and dynamic trials were collected. Subjects ran along a 25-m runway at a speed of 3.65 m/s (±5%), striking a force plate at its center. Running speed was monitored using photoelectric cells placed 2.86 m apart along the runway. Data for the stance phase of 5 running trials were collected. All subjects wore the same laboratory neutral (cushioning) running shoes.

Data Collection and Analysis

Kinematic data were collected with a 6-camera, 3-D VICON motion analysis system (Oxford Metrics, Ltd, Oxford, UK). The cameras were calibrated to a volume of 2.0 m^3, and calibration errors were all below 3 mm. Kinematic data were sampled at 120 Hz and low-pass filtered at 8 Hz with a fourth-order zero-lag Butterworth filter. Ground reaction forces data were collected using a force plate (Bertec Corporation, Columbus, OH) at a sampling frequency of 960 Hz and low-pass filtered at 50 Hz, with a fourth-order zero-lag Butterworth filter. Trials were normalized to 100% of stance and the 5 trials were averaged for each subject.

Visual3D software (C-Motion Inc, Rockville, MD) was used to calculate kinematic and kinetic variables. All lower extremity segments were modeled as a frustra of right cones model and anthropometric data provided by Dempster.[2] The kinematic and kinetic variables of interest were extracted from individual trials, selected from the first 60% of the stance phase of gait, and included ankle, knee, and hip joint 3-D kinematic and kinetic variables. The first 60% of stance was analyzed because, in general, peak joint moments, maximum ground reaction forces, and peak joint angles occur within this time frame. The specific kinematic variables of interest were (1) peak rearfoot eversion angle, (2) peak rearfoot invertor moment, (3) peak knee internal rotation angle, (4) peak knee external rotator moment, (5) peak hip adduction angle, (6) peak hip abductor moment, and (7) peak knee flexion angle. All moments were expressed as internal moments and normalized to body mass (Nm/kg). Data from the previously injured limb of the female runners in the ITBS group were used for analysis and were compared with the right limb of the female runners in the control group. Variables were statistically compared between groups using 1-way ANOVAs at a confidence level of .05.

TABLE 2 Kinematic and Kinetic Data for Iliotibial Band Syndrome (ITBS) Injured Limb Compared to the Control Group

Variables	ITBS*	Control*	Difference†	*P* Value
Rearfoot peak eversion angle (deg)	8.94 ± 3.16	10.04 ± 3.22	1.10 ± 0.06 (0.05, 2.17)	.16
Rearfoot peak invertor moment (Nm/kg)	0.14 ± 0.13	0.09 ± 0.08	0.05 ± 0.05 (0.02, 0.09)	.05‡
Knee peak internal rotation angle (deg)	1.75 ± 5.94	–1.14 ± 4.96	2.89 ± 0.98 (1.25, 4.86)	.03‡
Knee peak external rotator moment (Nm/kg)	0.09 ± 0.06	0.09 ± 0.05	0.00 ± 0.01 (–0.02, 0.02)	.68
Knee peak flexion angle (deg)	45.30 ± 4.50	45.21 ± 5.00	0.10 ± 0.50 (–1.56, 1.59)	.95
Hip peak adduction angle (deg)	10.39 ± 4.36	7.92 ± 5.84	2.47 ± 1.48 (0.54, 3.91)	.05‡
Hip peak abductor moment(Nm/kg)	1.33 ± 0.24	1.33 ± 0.18	0.00 ± 0.06 (–0.08, 0.06)	.94

* *Values are mean ± SD.*
† *Values are mean ± SD (95% CI).*
‡ *ITBS group significantly greater than the control group.*

RESULTS

A comparison summary of the kinematic and kinetic variables of interest for the ITBS injured limb and the limb of the control group is presented in **TABLE 2**. At the foot, the runners in the ITBS group exhibited similar peak rearfoot eversion angle (*P* =.16) but significantly greater peak rearfoot invertor moments (*P* =.05) compared to controls (**FIGURE 2**). At the knee, the runners in the ITBS group exhibited a significantly greater peak knee internal rotation angle (*P* =.03) but similar peak knee external rotator moment (*P* = .68) compared to controls (**FIGURE 3**). Peak knee flexion angle was similar between groups (*P* = .95). At the hip, the runners in the ITBS group exhibited a significantly greater hip adduction angle (*P* = .05) but no differences in peak hip abductor moment (*P* = .94) compared to controls (**FIGURE 4**).

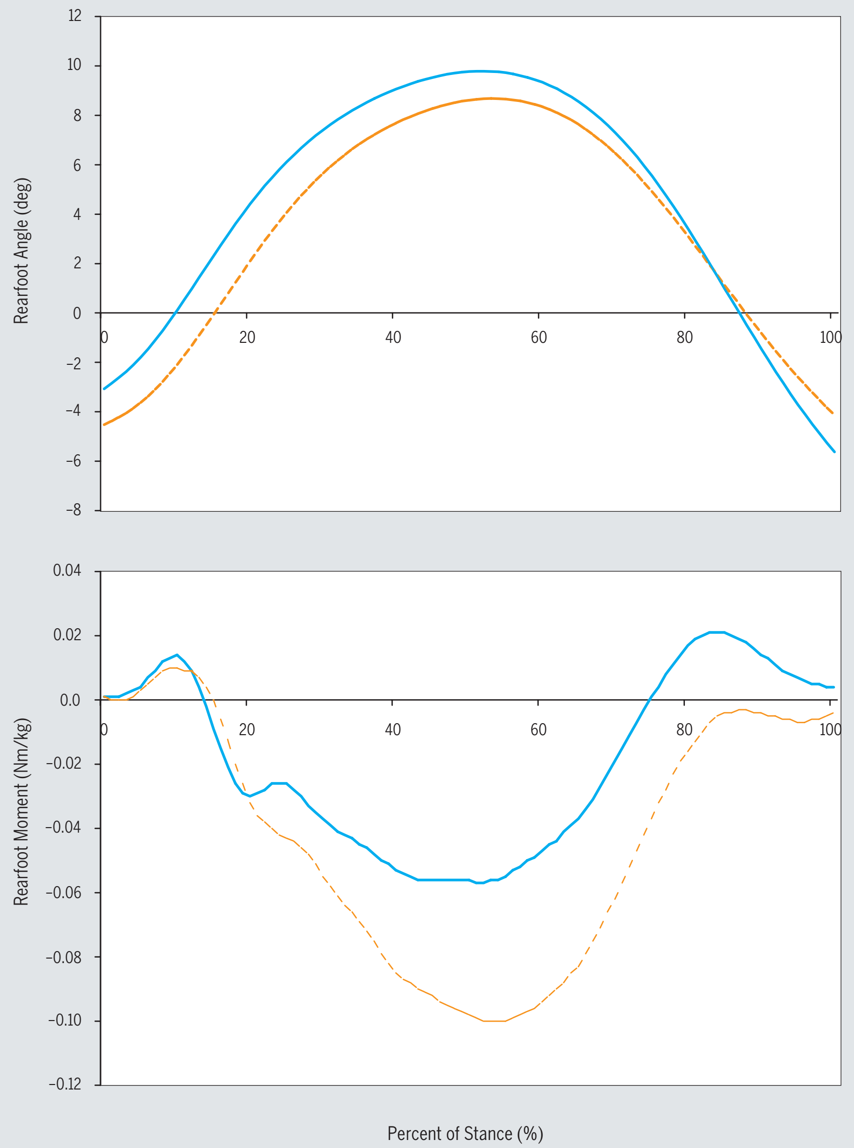

FIGURE 2. Rearfoot inversion/eversion angles (top graph) and moments (bottom graph) for the iliotibial band syndrome (dashed orange line) and control (solid blue line) groups during the stance phase of running. Positive values indicate rearfoot eversion and invertor moment.

DISCUSSION

THE PURPOSE OF THIS RETROSPECTIVE study was to examine differences in running mechanics between runners with a history of ITBS and runners with no history of running-related knee injuries. Compared to previous studies in this area, we chose to conduct a comprehensive assessment including hip, knee, and rearfoot mechanics.

At the knee, the peak flexion angle was not different between groups. This finding provides further evidence that knee flexion, by itself, does not play a significant role in the aetiology of ITBS as has been historically believed.[1,21,23] However, the increased peak knee internal rotation angle in the ITBS group measured in the current study is likely an important factor in the development of ITBS. A number of authors have suggested that, due to its insertion on the tibia, increased knee rotation increases torsional loads to the tissues of the knee joint such as the iliotibial band.[6,10,14,18,20,28] In addition, Terry et al[27] suggested that the iliotibial band provides a significant amount of rotational restraint at the knee joint, increasing the potential for injury with increases in knee joint transverse plane motion. Our results are consistent with those provided by Miller et al,[16] who reported that runners with a history of ITBS exhibited a greater peak knee internal rotation velocity at the beginning and end of an exhaustive run compared to controls. Similar to the results of the current study, Miller et al[16] and Noehren et al[22] also reported that the runners with a history of ITBS remained more internally rotated at the knee throughout stance compared to noninjured runners (**FIGURE 3**). However, an exhaustive run protocol was not used in the current study, so comparisons with the data of Miller et al[16] must be made with caution.

Numerous authors have suggested that greater rearfoot eversion can lead to knee-related injuries, including ITBS.[14,18,20,28] However, greater rearfoot eversion in the group with a history of ITBS was not found in the current study. In fact, the runners in the ITBS group exhibited slightly lower peak eversion values compared to the control group, which is similar to the results from the prospective study by Noehren et al.[22] Similarly, Messier et al[15] reported that runners with a history of ITBS exhibited reduced rearfoot eversion during heelstrike compared to healthy runners. Interestingly, in our study, the rearfoot invertor moment was significantly higher in the ITBS group. It is possible that the increased rearfoot invertor moment reflects a compensatory mechanism to try to control eversion and the associated tibial and knee internal rotation. Moreover, strain on the iliotibial band is related to motion of the tibia and not necessarily motion of the rearfoot. The fact that the foot eversion-tibial rotation ratio is not a 1:1 relationship and varies

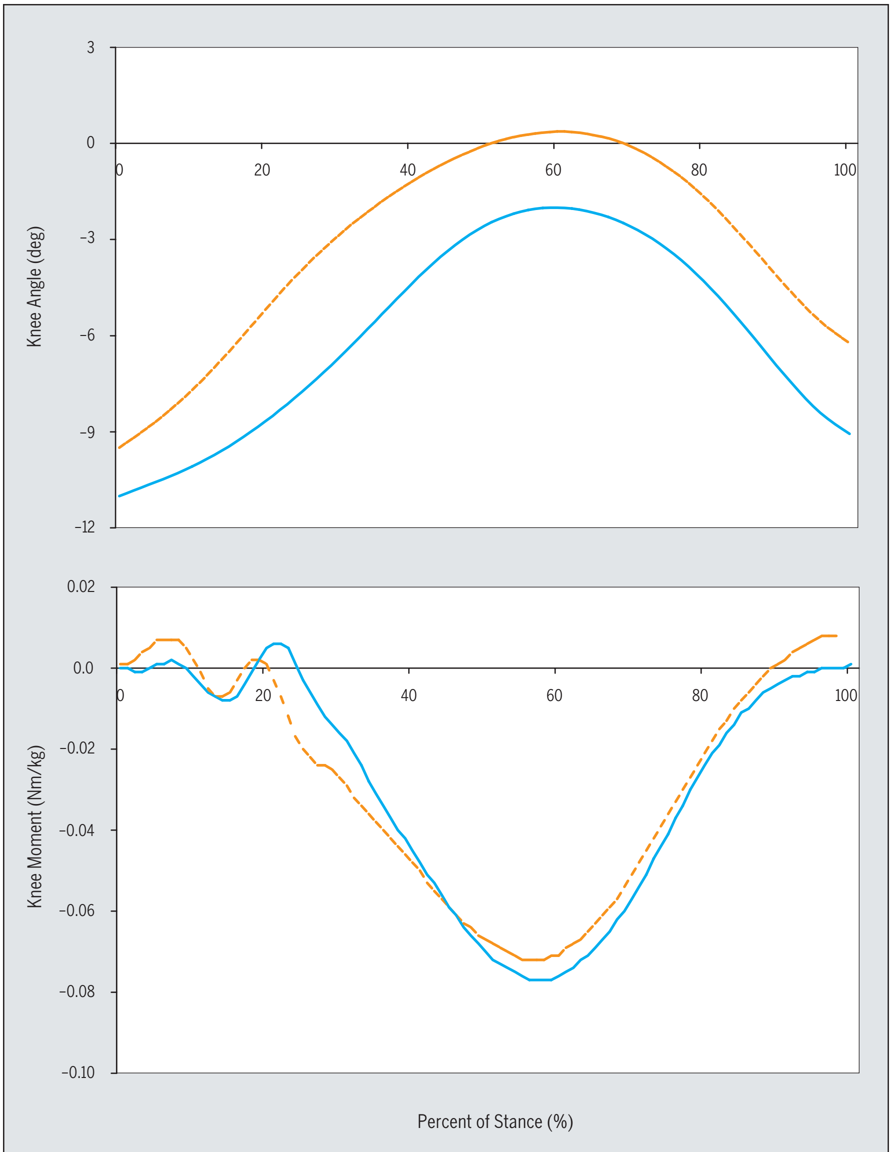

FIGURE 3. Knee internal/external rotation angles (top graph) and moments (bottom graph) for the iliotibial band syndrome (dashed orange line) and control (solid blue line) during the stance phase of running. Positive values indicate knee internal rotation and internal rotator moment.

from person to person[7,11,13] may explain why eversion was not different between groups. Finally, the greater rearfoot invertor moment could be associated with the greater inversion angle observed at heel strike (**FIGURE 2**), which appears to be approximately 2° to 3° greater for the ITBS group compared to controls.

Consistent with our hypothesis, the ITBS group exhibited a significantly greater peak hip adduction angle compared to controls. As with knee internal rotation, the runners with a previous history of ITBS remained in greater hip adduction throughout stance (**FIGURE 4**). Due to the insertion of the iliotibial band at the distal femur, increased hip adduction can result in greater tensile strain to this tissue. Coupled with the torsional strain due to increased knee internal rotation angle, increased hip adduction may place the iliotibial band at further risk for irritation as it slides across the lateral femoral condyle. In fact, Fairclough et al[4] evaluated the clinical anatomy of the iliotibial band and suggested that the combination of tensile loading from hip adduction and torsional loading from knee internal rotation may result in greater tissue strain than either of these types of loads in isolation. Using a musculoskeletal model of the lower extremity based on the kinematics from the exhaustive run, Miller et al[16] reported that strain in the iliotibial band was higher for the ITBS runners throughout all of stance and from the beginning to the end of the exhaustive run compared to controls. These authors attributed this increased strain primarily to the torsional stress experienced at the knee joint.

The increased hip adduction position was expected to be associated with greater demands on the hip abductor muscles, resulting in a greater hip abductor moment. However, this hypothesis was not supported. These results are, however, consistent with the results of the prospective ITBS study by Noehren et al,[22] who also reported no differences and nearly identical patterns in the hip abductor moment between runners who developed ITBS and controls. It is possible that the timing of muscle activation is more important in controlling hip adduction than the magnitude of activation. Future studies, possibly using electromyographic monitoring, are necessary to answer these questions.

Increased hip adduction and knee internal rotation, likely resulting in increased strain to the iliotibial band, may result from hip muscle weakness. Fredricson et al[8] reported that runners with ITBS exhibited significantly reduced hip abductor muscle strength in the affected limb compared to healthy controls. These authors also reported that following a 6-week hip abductor muscle-strengthening program, 22 of 24 patients with ITBS demonstrated a 34.9% to 51.4% increase in muscle strength, and were free of ITBS pain while running. Thus, weakness of the hip abductor muscles may result in greater hip adduction and knee internal

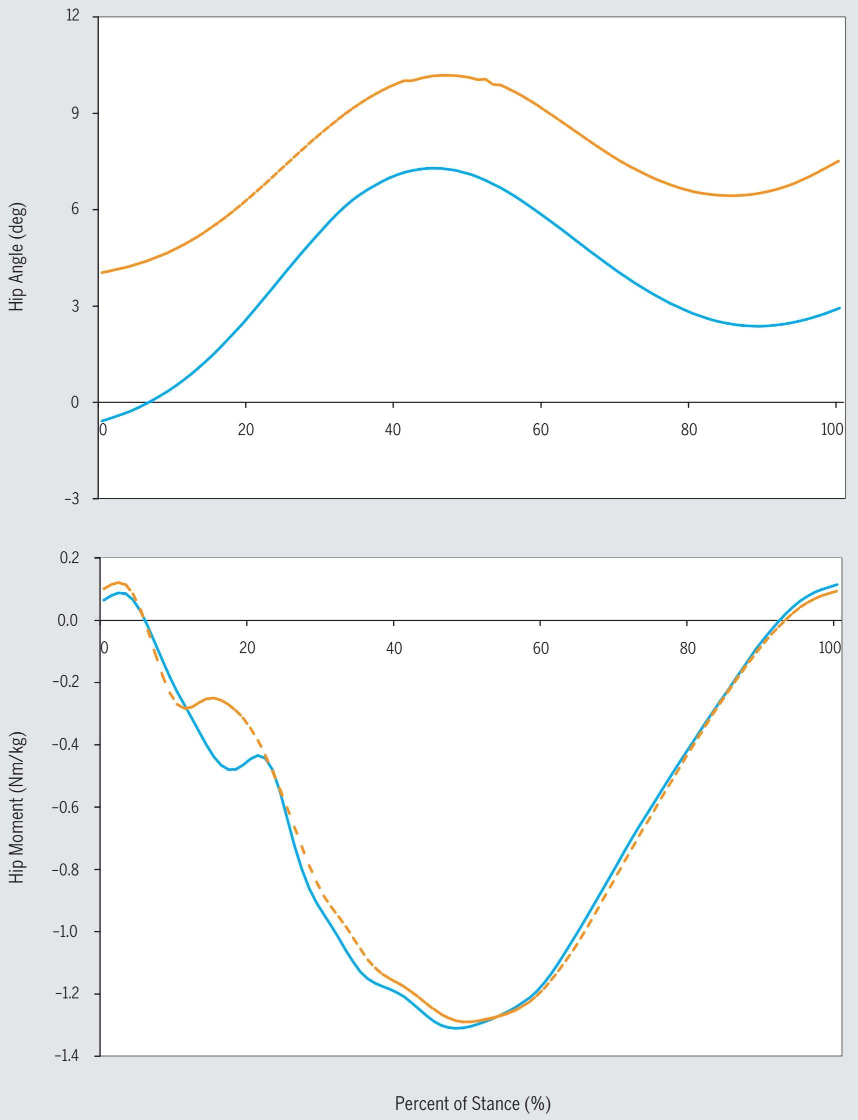

FIGURE 4. Hip abduction/adduction angles (top graph) and moments (bottom graph) for the iliotibial band syndrome (dashed orange line) and control (solid blue line) groups during the stance phase of running. Positive values indicate hip adduction and adductor moment.

rotation during the stance phase of running and increased strain to the iliotibial band. While the current study did not measure hip abductor muscle strength, future studies should include hip abductor strength measures to better elucidate the possible aetiology of ITBS.

It is encouraging to note that these overall findings were consistent with the results of a recently published prospective study of ITBS by Noehren et al,[22] conducted in the same laboratory under similar conditions but with different subjects. The current retrospective study also noted a significant increase in the rearfoot invertor moment in the ITBS group, which may indicate a compensatory mechanism following injury. However, aside from this variable, these results begin to suggest that lower extremity gait mechanics do not change as a result of ITBS. Moreover, the similar results of the current study and those of Noehren et al[22] suggest that the aetiology of ITBS is more related to atypical hip and knee mechanics as compared to foot mechanics. Therefore, the current retrospective study provides further evidence linking atypical lower extremity kinematics and ITBS.

Additional limitations and delimitations in this study are recognized. First, the runners in the ITBS group were injury-free at the time of testing but did have a history of ITBS that was confirmed by a medical professional. However, the subjects involved in the current study were similar to those of Miller et al,[16] who were also pain-free at the time of testing. Second, the participants in the present investigation all ran within a running speed range of 3.65 m/s (±5%). However, the running speed range chosen was a comfortable pace for all the subjects and was similar to their own regular training pace. Third, the anthropometric model used to calculate the kinetic variables of interest was not specific to female subjects. Using a model that accounts for the true mass segment properties of females may influence the results of the study. However, because the data were normalized to subject mass and height, this limitation was reduced. It is acknowledged that future studies using an anthropometric model specific to female subjects may provide slightly different results.

CONCLUSION

Female recreational runners who had previously sustained ITBS exhibited significantly greater stance phase peak hip adduction and peak knee internal rotation angles, and greater rearfoot invertor moments compared to a control group during running. These results were generally similar to those reported for a prospective study conducted within the same laboratory environment with a separate group of subjects. The common results between the prospective study and the current retrospective study provide strong evidence related to atypical running mechanics and the aetiology of ITBS.

KEY POINTS

FINDINGS: During running, stance phase peak hip adduction angles, peak knee internal rotation angles, and greater rearfoot invertor moments were significantly greater in female recreational runners who had previously sustained ITBS compared to a control group.

IMPLICATION: Our results suggest that correction of atypical lower extremity kinematics may decrease iliotibial band stress/strain and should be considered in the treatment of persons with ITBS.

CAUTION: Our study was retrospective in design and, as such, statements concerning cause and effect cannot be made.

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REFERENCES

1. Birnbaum K, Siebert CH, Pandorf T, Schopphoff E, Prescher A, Niethard FU. Anatomical and biomechanical investigations of the iliotibial tract. *Surg Radiol Anat.* 2004;26:433-446. http://dx.doi.org/10.1007/s00276-004-0265-8
2. Dempster WT. Space requirements of the seated operator: geometrical, kinematic, and mechanical aspects of teh body with special references to the limbs. *WADC Technical Report.* 1955;55-159.
3. Duffey MJ, Martin DF, Cannon DW, Craven T, Messier SP. Etiologic factors associated with anterior knee pain in distance runners. *Med Sci Sports Exerc.* 2000;32:1825-1832.
4. Fairclough J, Hayashi K, Toumi H, et al. The functional anatomy of the iliotibial band during flexion and extension of the knee: implications for understanding iliotibial band syndrome. *J Anat.* 2006;208:309-316. http://dx.doi.org/10.1111/j.1469-7580.2006.00531.x
5. Ferber R, Davis I, Hamil J, Pollard CD. Prospecitve biomechanical investigation of iliotibial band syndrome in competitive female runners [abstract]. *Med Sci Sports Exerc.* 2003;35:S91.
6. Ferber R, Davis IM, Williams DS, 3rd. Effect of foot orthotics on rearfoot and tibia joint coupling patterns and variability. *J Biomech.* 2005;38:477-483. http://dx.doi.org/10.1016/j.jbiomech.2004.04.019
7. Ferber R, Davis IM, Williams DS, 3rd. Gender differences in lower extremity mechanics during running. *Clin Biomech (Bristol, Avon).* 2003;18:350-357.
8. Fredericson M, Cookingham CL, Chaudhari AM, Dowdell BC, Oestreicher N, Sahrmann SA. Hip abductor weakness in distance runners with iliotibial band syndrome. *Clin J Sport Med.* 2000;10:169-175.
9. Hamill J, van Emmerik RE, Heiderscheit BC, Li L. A dynamical systems approach to lower extremity running injuries. *Clin Biomech (Bristol, Avon).* 1999;14:297-308.
10. Horton MG, Hall TL. Quadriceps femoris muscle angle: normal values and relationships with gender and selected skeletal measures. *Phys Ther.* 1989;69:897-901.
11. Inman VT. *The Joints of the Ankle.* Baltimore, MD: Williams & Wilkins; 1976.
12. Ireland ML, Willson JD, Ballantyne BT, Davis IM. Hip strength in females with and without patellofemoral pain. *J Orthop Sports Phys Ther.* 2003;33:671-676.
13. Lundberg A, Svensson OK, Bylund C, Goldie I, Selvik G. Kinematics of the ankle/foot complex--Part 2: Pronation and supination. *Foot Ankle.* 1989;9:248-253.
14. McClay I, Manal K. A comparison of three-dimensional lower extremity kinematics during running between excessive pronators and normals. *Clin Biomech (Bristol, Avon).* 1998;13:195-203.
15. Messier SP, Edwards DG, Martin DF, et al. Etiology of iliotibial band friction syndrome in distance runners. *Med Sci Sports Exerc.* 1995;27:951-960.
16. Miller RH, Lowry JL, Meardon SA, Gillette JC. Lower extremity mechanics of iliotibial band syndrome during an exhaustive run. *Gait Posture.* 2007;26:407-413. http://dx.doi.org/10.1016/j.gaitpost.2006.10.007
17. Moore KL, Dalley AF. *Clinically Oriented Anatomy.* 5th ed. Philadelphia, PA: Lippincott Williams & Wilkins; 2005.
18. Nawoczenski DA, Saltzman CL, Cook TM. The effect of foot structure on the three-dimensional kinematic coupling behavior of the leg and rear foot. *Phys Ther.* 1998;78:404-416.
19. Niemuth PE, Johnson RJ, Myers MJ, Thieman TJ. Hip muscle weakness and overuse injuries in recreational runners. *Clin J Sport Med.* 2005;15:14-21.
20. Nigg BM, Cole GK, Nachbauer W. Effects of arch height of the foot on angular motion of the lower extremities in running. *J Biomech.* 1993;26:909-916.
21. Noble CA. Iliotibial band friction syndrome in runners. *Am J Sports Med.* 1980;8:232-234.
22. Noehren B, Davis I, Hamill J. ASB clinical biomechanics award winner 2006 prospective study of the biomechanical factors associated with iliotibial band syndrome. *Clin Biomech (Bristol, Avon).* 2007;22:951-956. http://dx.doi.org/10.1016/j.clinbiomech.2007.07.001
23. Orchard JW, Fricker PA, Abud AT, Mason BR. Biomechanics of iliotibial band friction syndrome in runners. *Am J Sports Med.* 1996;24:375-379.
24. Sommer C, Hintermann B, Nigg BM, van den Bogert AJ. Influence of ankle ligaments on tibial rotation: an in vitro study. *Foot Ankle Int.* 1996;17:79-84.
25. Souza RB, Powers CM. Differences in hip kinematics, muscle strength, and muscle activation between subjects with and without patellofemoral pain. *J Orthop Sports Phys Ther.* 2009;39:12-19. http://dx.doi.org/10.2519/jospt.2009.2885
26. Taunton JE, Ryan MB, Clement DB, McKenzie DC, Lloyd-Smith DR, Zumbo BD. A retrospective case-control analysis of 2002 running injuries. *Br J Sports Med.* 2002;36:95-101.
27. Terry GC, Hughston JC, Norwood LA. The anatomy of the iliopatellar band and iliotibial tract. *Am J Sports Med.* 1986;14:39-45.
28. Williams DS, 3rd, McClay IS, Hamill J. Arch structure and injury patterns in runners. *Clin Biomech (Bristol, Avon).* 2001;16:341-347.