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Prospective study of the biomechanical factors associated with iliotibial band syndrome

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Abstract

Background. Iliotibial band syndrome is the leading cause of lateral knee pain in runners. Despite its high prevalence, little is known about the biomechanics that lead to this syndrome. The purpose of this study was to prospectively compare lower extremity kinematics and kinetics between a group of female runners who develop iliotibial band syndrome compared to healthy controls. It was hypothesized that runners who develop iliotibial band syndrome will exhibit greater peak hip adduction, knee internal rotation, rearfoot eversion and no difference in knee flexion at heel strike. Additionally, the iliotibial band syndrome group were expected to have greater hip abduction, knee external rotation, and rearfoot inversion moments.

Methods. A group of healthy female recreational runners underwent an instrumented gait analysis and were then followed for two years. Eighteen runners developed iliotibial band syndrome. Their initial running mechanics were compared to a group of age and mileage matched controls with no history of knee or hip pain. Comparisons of peak hip, knee, rearfoot angles and moments were made during the stance phase of running. Variables of interest were averaged over the five running trials, and then averaged across groups.

Findings. The iliotibial band syndrome group exhibited significantly greater hip adduction and knee internal rotation. However, rearfoot eversion and knee flexion were similar between groups. There were no differences in moments between groups.

Interpretation. The development of iliotibial band syndrome appears to be related to increased peak hip adduction and knee internal rotation. These combined motions may increase iliotibial band strain causing it to compress against the lateral femoral condyle. These data suggest that treatment interventions should focus on controlling these secondary plane movements through strengthening, stretching and neuromuscular re-education.

Keywords: Running mechanics; Iliotibial band syndrome; Lateral knee pain

1. Introduction

Iliotibial band syndrome (ITBS) is the leading cause of lateral knee pain in runners (Taunton et al., 2002). This syndrome is believed to result from friction of the iliotibial band (ITB) as it slides over the lateral femoral condyle (Orchard et al., 1996). Biomechanical factors which result in increasing the strain of the ITB may contribute to the development of this injury (Fredickson et al., 2000). While, the relationship between running mechanics and ITBS is not well understood, proximal, local, and distal factors have all been investigated.

Proximally, the ITB acts as a lateral hip stabilizer resisting hip adduction (Fredickson et al., 2000). It originates in the facial components of the gluteus maximus, gluteus medius, and tensor fasciae latae muscles (Muhle et al.,

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1999; Birnbaum et al., 2004; Terry et al., 1986). The ITB is attached distally to the supracondyle tubercle of the femur and the lateral intramuscular septum. In addition it has fibers that attach to the patella (Muhle et al., 1999; Birnbaum et al., 2004; Terry et al., 1986). Due to these attachments, increased hip adduction is likely to lead to increased tension on the ITB. Increased hip adduction may necessitate a greater eccentric demand from gluteal musculature, resulting in a higher hip abduction moment. In fact, Fredickson et al. (2000) reported that runners who currently have ITBS exhibited weak hip abductors. Since their subjects were already injured at the time of the measurement, it is unclear whether the weakness was the cause or result of the ITBS. However, it is interesting to note that the ITBS symptoms were resolved in 90% of the subjects following a six week program of hip abductor strengthening (Fredickson et al., 2000).

Local factors, those related to mechanics of the knee joint, have also been examined. ITBS has been associated with lateral knee pain that occurs just after heel strike when the knee is in approximately 20° of flexion (Orchard et al., 1996). This pain has been reported to be exacerbated with downhill running (Orchard et al., 1996; Noble, 1980). During downhill running, an individual lands in near extension and moves through greater knee flexion excursion than in level running. It has been suggested that an impingement zone exists between 20–30° of knee flexion. In this range, the distal fibers of the ITB are believed to compress and slide over the lateral femoral condyle (Orchard et al., 1996). This proposed mechanism led Orchard et al. (1996) to examine sagittal plane knee mechanics of runners with ITBS. Interestingly, they found no differences in knee flexion at foot strike, peak knee flexion, or in the percent of time spent in knee flexion in runners with ITBS compared to their non-injured leg (Orchard et al., 1996). This suggests that knee motions, other than those in the sagittal plane, may contribute to the development of ITBS. With attachments at the lateral femoral condyle and at Gerdy's tubercle, the ITB is likely strained with internal rotation of the knee. However, only one previous retrospective investigation has addressed knee internal rotation. These authors found that knee internal rotation was significantly greater in runners with a history of ITBS as compared to the healthy controls (Noehren et al., 2006). The combination of increased knee internal rotation angle, and an associated high external rotation moment could place greater demands on passive structures that control internal rotation.

Distal factors may also play a role in ITBS. Increased rearfoot eversion, with associated talar adduction, results in increased tibial internal rotation (Lundberg et al., 1989). With its attachment to Gerdy's tubercle, the ITB is elongated as the tibia internally rotates. While this distal mechanism of ITBS seems logical, evidence to support it is contradictory. Messier et al. (1995) reported that runners with ITBS exhibited twice the peak rearfoot movement as compared to controls. While not measured in their study, this increased eversion may be associated with greater eccentric demands of the inverter muscles due to high inverter moment. Noehren et al. (2006) found that runners with a history of ITBS exhibited decreased peak rearfoot eversion. Therefore, the distal mechanism involving increased rearfoot eversion needs further examination.

In summary, the etiology of ITBS is still unclear. Evidence to date does not support a sagittal plane knee mechanism. Retrospective studies suggest that proximal and distal mechanisms may be involved in the development of ITBS. However, there are no prospective studies of lower extremity kinematics and kinetics in runners who develop ITBS. Therefore, the purpose of this prospective investigation was to compare the pre-existing frontal and transverse plane lower extremity kinematics and kinetics between a group of female runners who develop ITBS compared to healthy controls. It was hypothesized that runners who go on to develop ITBS will initially exhibit greater hip adduction, knee internal rotation and rearfoot eversion angles. Additionally, no difference in knee flexion at heel strike was expected between groups. Lastly, it was hypothesized that the ITBS subjects would have greater hip abduction, knee external rotation, and ankle inversion moments.

2. Methods

The subjects in this study are part of a larger, ongoing, prospective investigation of lower extremity injuries in female runners. To be included, all subjects ran a minimum of 20 miles a week, were between the ages of 18–45, and were free from any injuries at the time of data collection. Prior to participation, each subject signed a consent form approved by the University's Human Subjects Compliance Committee.

The bilateral 3D lower extremity kinematics and kinetics during running were then collected. Retro-reflective markers were attached to the pelvis, thigh, shank and foot. Pelvic tracking markers were placed on the space between the fifth lumbar vertebrae and the sacrum, the iliac crests and the anterior superior iliac spines. Molded thermoplastic shells with four non-collinear markers were attached to the proximal thigh and distal shank. Two markers were placed on the shoe along the vertical bisection of the heel. An additional marker was placed on the lateral side of the heel. Anatomical markers were placed over the greater trochanter, medial and lateral femoral epicondyle, medial and lateral malleoli, first and fifth metatarsal heads and the front end of the shoe. All subjects wore a standard neutral running shoe. Subjects ran along a 25 m run way at a speed of 3.7 m/s (±5%) striking a force plate at its center. Kinematic data were collected at 120 Hz with a 6 camera Vicon 512 motion analysis system (Oxford Metrics Ltd, Oxford, UK) and low-pass filtered at 8 Hz with a fourth-order zero lag Butterworth filter. Force data was sampled at 1080 Hz and low-pass filtered at 50 Hz with a fourth-order zero lag

Butterworth filter. Five acceptable trials were collected during the stance phase of running.

A detailed injury history was then recorded. Subjects were followed monthly by email for two years, and reported any running related injuries as well as their monthly mileage. An apriori power analysis ($B = 0.20$, $P = 0.05$) indicated that a minimum of 14 subjects per group would be needed. A total of 400 subjects were recruited over a period of four years. The incidence rate of ITBS was 16% among all reported injuries. From the larger group 18 runners had developed ITBS since beginning the study. All included injuries were required to be diagnosed by a medical professional, such as a physician, physical therapist or athletic trainer. All subjects in the control group were free from any previous hip or knee injury. Subjects in the ITBS group had no history of hip or knee injury prior to their ITBS. Eighteen age and mileage matched runners were chosen for the control group. The injured leg of the ITBS group was compared to the right leg of the control group.

Kinematic and kinetic data were processed using Visual3D software (C-motion, Rockville, MD, USA). The lower extremity segments were modeled as a frustra of right cones with anthropometric data from Dempster (1959). Moments were calculated at the proximal end of the distal segment of each joint. Foot strike was identified as the point when the vertical ground reaction force exceeded 20 N. Toe off was identified when the force went below 20 N. Discrete variables were extracted from each individual trial. All trials were then time normalized across stance and averaged for each subject. The mean curves were then averaged across groups to produce ensemble curves.

Data were statistically analyzed using SPSS (SPSS Inc., Chicago, IL, USA). Independent t-tests were conducted ($\alpha < 0.05$) to test the hypotheses. The kinematic variables of interest were peak rearfoot eversion, knee internal rotation, hip adduction and knee flexion at heel strike. Additionally, tibial internal rotation (in global) and femoral rotation (in global) were assessed to further explore the data. The kinetic variables of interest were peak rearfoot inversion, knee external rotation and hip abduction moments.

3. Results

The age, monthly mileage, and body mass index (BMI) of the ITBS and control groups are presented in Table 1.

Table 1
Age, average monthly mileage, and body mass index (BMI) for the ITBS group compared to the control (CON) group

	ITBS	CON
Age	26.8	28.5
Monthly mileage	96.2	99.3
BMI	21.9	22.1

An outlier analysis was performed to remove any subjects whose data were greater than three standard deviations from the mean (Newton and Rudestam, 1999; Winer et al., 1991). In the control group, this resulted in the removal of two outliers for knee internal rotation, one for rearfoot eversion, two for rearfoot inversion moment and two for knee external rotation moment. In the ITBS group, one outlier was removed for knee internal rotation and hip adduction. The angular trajectories and variables of interest are presented in Figs. 1–4 and Table 2, respectively. The ITBS group visually landed in greater hip adduction and remained more adducted throughout stance (Fig. 2a). Peak hip adduction angle was also found to be significantly greater. However, hip abduction moment was not different and both groups exhibited nearly identical patterns (Fig. 2b).

There was not a significant difference ($P = 0.178$) in knee flexion at heel strike between groups (Fig. 1). However, visual inspection of Fig. 3a shows the ITBS group landed in greater internal rotation and remained more internally rotated throughout stance. In addition, the ITBS group had a significantly higher peak knee internal rotation angle ($P = 0.01$). To further understand whether this was related to a proximal or a distal mechanism, we also assessed segmental rotation of the tibia and femur. Tibial internal rotation was lower in the ITBS group by 2.2°, but this difference was not significant. However, femoral external rotation was significantly greater in the ITBS group.

At the rearfoot, the ITBS group landed in slightly more inversion, but exhibited a very similar pattern to the control group throughout stance (Fig. 4a). A trend ($P = 0.07$) towards lower peak eversion (by 2°) in the ITBS group was seen. However, there was no significant difference in rearfoot inversion moment between groups ($P = 0.66$). In light of the greater knee internal rotation seen in ITBS group, we were surprised to find that they exhibited lower peak rearfoot eversion. We further examined the data to

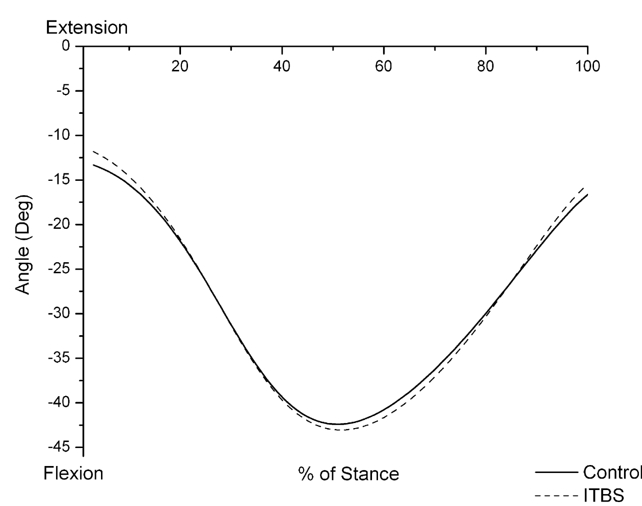

Fig. 1. Comparison of stance phase knee flexion between groups.

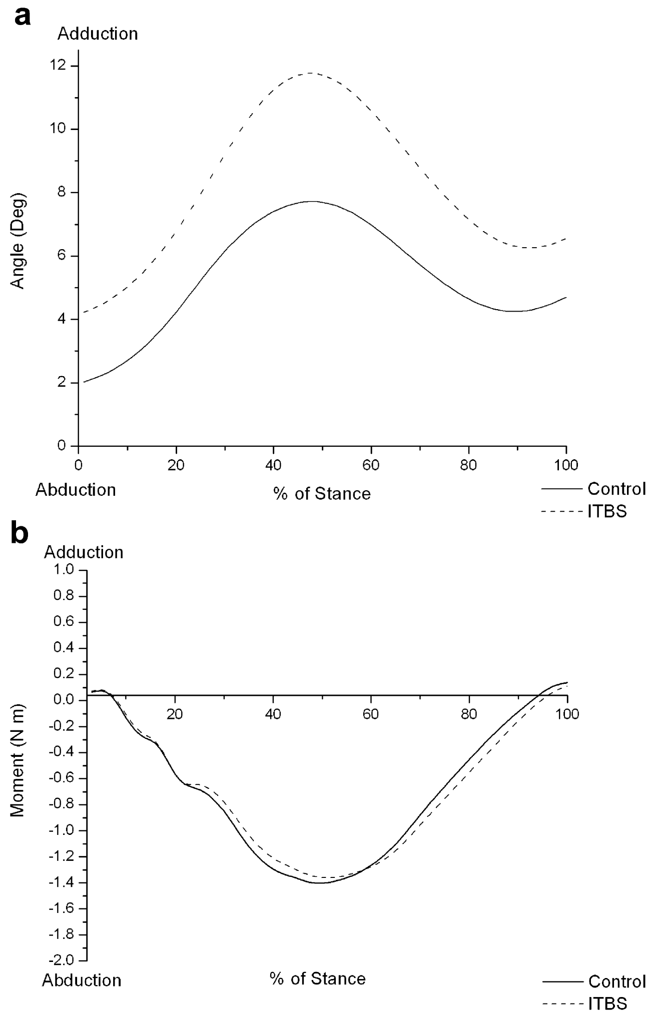

Fig. 2. Comparisons of stance (a) hip adduction and (b) hip abduction moment between groups.

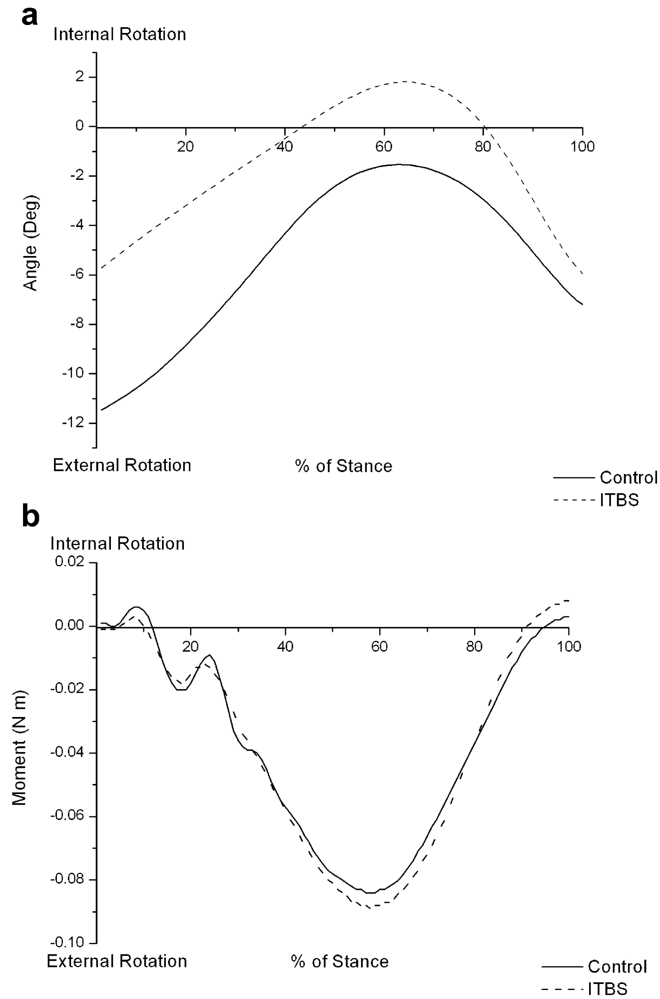

Fig. 3. Comparison of stance phase (a) knee internal rotation and (b) knee external rotation moment between groups.

determine whether there was a subgroup of subjects who exhibited the distal mechanism of excessive rearfoot eversion and knee internal rotation. To do this, we identified the ITBS subjects whose peak rearfoot motion was greater than the mean of the ITBS group (9.7°). These four subjects with the greatest rearfoot eversion (mean 12.7°) also had higher tibial internal rotation (11.7°) than the rest of the group (6.9°).

4. Discussion

The aim of this prospective study was to compare the lower extremity kinematics and kinetics of female runners who develop ITBS to those of healthy controls. In support of our hypotheses, we found the ITBS group exhibited greater hip adduction and knee internal rotation. However, the ITBS group unexpectedly exhibited less rearfoot eversion than the controls. Also, we found no significant differences in any of the moments.

The increased hip abduction in the ITBS group was consistent with our previous retrospective study (Noehren et al., 2006). ITB strain is likely to increase with adduction due to the distal attachments at the lateral femoral condyle. This increase could be due to hip weakness resulting in the inability to control hip abduction. In support of this, Fredickson et al. (2000) reported hip abductor weakness in a group of runners with ITBS compared to a control group. In addition, Niemuth et al. (2005) found that runners with a variety of overuse injuries, including ITBS, exhibited weak hip abductors on the injured leg. However, both of these studies were cross-sectional. Therefore, the weakness noted may have been a result of the injury as opposed to the cause. We expected that the increased hip adduction would place greater eccentric demands on the hip abductors, resulting in an increased abduction moment. While this was not found it is possible that differences in timing, rather than magnitude of activation may be present between groups. This would require an electromyographic assessment, which was not considered in this study.

The increased knee internal rotation exhibited by the ITBS group was also consistent with our previous retrospective study (Noehren et al., 2006). With its attachments

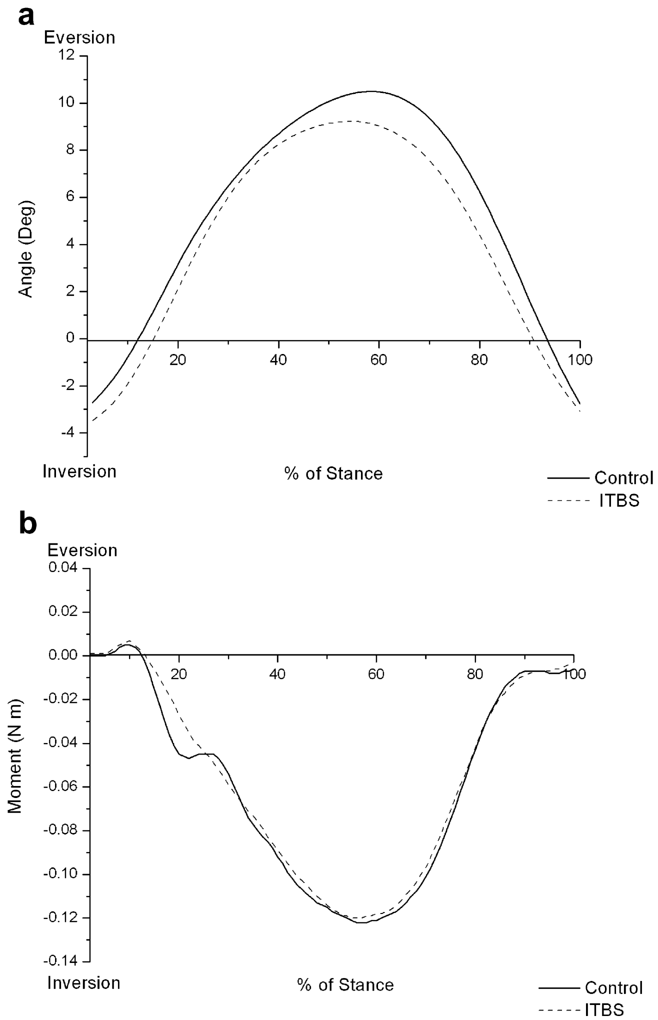

Fig. 4. Comparison of stance phase (a) rearfoot eversion ensemble curve and (b) rearfoot inversion moment between groups.

Table 2
Kinematic and kinetic of interest: mean (SD), *P*-value for the ITBS group compared to the control (CON) group

	ITBS	CON	*P*-value
Hip adduction peak (deg)	14.1 (2.5)	10.6 (5.1)	0.01
Hip abduction moment (Nm)	−1.4 (0.37)	−1.3 (0.19)	0.56
Knee internal rotation peak (deg)	3.9 (3.7)	0.02 (4.6)	0.01
Knee external rotation moment (Nm)	−0.12 (0.12)	−0.09 (0.05)	0.42
Rearfoot eversion peak (deg)	9.7 (3.3)	11.6 (2.5)	0.07
Rearfoot inversion moment (Nm)	−0.15 (0.10)	−0.13 (0.09)	0.66
Tibia in lab peak (deg)	6.9 (4.4)	9.1 (5.4)	0.23
Femur in lab peak (deg)	−4.6 (6.9)	1.3 (7.5)	0.02
Knee flexion at heel strike (deg)	−11.8 (4.78)	−14.4 (6.03)	0.178

at Gerdy's tubercle, increased knee internal rotation moves the attachment of the ITB medial. This is likely to further increase its compression against the lateral femoral condyle. Using MRI imaging, Fairclough et al. (2006) has recently shown that, as the knee flexes and internally rotates, the ITB compresses into the lateral femoral condyle. There is no bursa to protect the ITB from shear as it passes over the lateral femoral condyle (Fairclough et al., 2006; Muhle et al., 1999). Therefore, individuals with excessive internal rotation may be vulnerable to irritation of the ITB. During the first half of stance, the knee is internally rotating in the presence of an external rotation moment. Thus, the external rotation moment serves to decelerate the internal rotation. Although, not statistically significant, we did find that the ITBS group had 25% greater knee external rotation moment. Terry et al. (1986) has proposed that the ITB is one of the primary rotational restraints at the knee, which places it at risk for injury with the repetitive loading of running.

Knee internal rotation occurs from either tibial internal rotation or femoral external rotation. Surprisingly, while knee internal rotation was greater in the ITBS group, tibial internal rotation was less than the controls. However, further examination revealed that greater femoral external rotation led to greater knee internal rotation observed. This increased external rotation seen in the ITBS group may be related to muscle imbalances at the hip. Co-contraction of the internal and external rotators is necessary to provide stability to the femoral head in the acetabulum during loading (Gottschalk et al., 1989). The gluteus minimus, anterior fibers of the gluteus medius and tensor fascia latae all serve to abduct and internally rotate the femur (Gottschalk et al., 1989; Pare et al., 1981). Insufficient activity of these muscles can lead to the increased femoral external rotation.

Our findings related to rearfoot eversion are consistent with those of Noehren et al. (2006). The ITBS groups landed in less eversion and remained less everted throughout stance (Fig. 3a). This is consistent with the lower tibial internal rotation seen as, these motions are coupled (Lundberg et al., 1989). By comparison, Messier et al. (1995) reported greater peak rearfoot eversion in the ITBS group. However, it is difficult to make direct comparisons as these authors utilized a 2D approach which is susceptible to perspective error.

While the ITBS group as a whole demonstrated reduced eversion, a subgroup of subjects did demonstrate excessive eversion. The four ITBS subjects with highest rearfoot eversion also exhibited high tibial internal rotation and knee internal rotation. This suggests that these particular subjects did exhibit a distal mechanism for ITBS. These are the runners who might benefit from an intervention to control rearfoot motion, such as foot orthoses.

Prospective studies are the benchmark for establishing cause and effect relationships. However, these studies are costly in terms of subject recruitment and follow-up. Therefore, it was encouraging to find that these prospective data were consistent with previously reported retrospective data (Noehren et al., 2006). Specifically, both studies found increased hip adduction and knee internal rotation, and reduced rearfoot eversion in the ITBS group. The similarity in these results suggests that runners with ITBS may not change their mechanics as a result of their injury, and that retrospective studies of this group may, very well, be adequate.

In conclusion, female recreational runners who go onto develop ITBS exhibited greater hip adduction and peak knee internal rotation. These results suggest that interventions should be aimed at improving the strength and neuromuscular control of the hip. Interventions should also include ITB stretching to increase the overall compliance of ITB.

Conflict of Interest

The authors have no personal or financial conflict interest that influenced this work.

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