


Kinematics of recreational runners with iliotibial band injury

BRUNO SUÁREZ LUGINICK , JAVIER RUEDA OJEDA, CÉSAR COLLAZO GARCÍA, SANTIAGO VEIGA FERNÁNDEZ, ENRIQUE NAVARRO CABELLO

Faculty of Sports Sciences, Technical University of Madrid, Spain

ABSTRACT

According to the literature, the risk of developing iliotibial band syndrome (ITBS) is related to the running technique of each runner. The purpose of this study was to investigate whether differences exist in the running technique of runners with ITBS and healthy runners. The sample was composed of 60 recreational runners (30 healthy runners and 30 with ITBS). A 3D kinematic analysis was performed to measure 3D joint angles of the lower limb. Reaction forces in the stance phase of running were also determined. Runners in the ITBS group exhibited significantly lower contact time, knee valgus, peak knee flexion and hip rotation. Of note, gender-based differences were observed. No differences were found between groups in hip adduction angle, tibial internal rotation and foot kinematics. The runners with current ITBS showed an altered kinematic profile. Male and female runners with ITBS showed different alterations in running kinematics. These results suggest that gender should be considered when investigating the biomechanical etiology of ITBS. **Key words:** HIP, BIOMECHANICS, RUNNING, KNEE, PREVENTION.

Cite this article as:

Suárez Luginick, B., Rueda Ojeda, J., Collazo García, C., Veiga Fernández, S., & Navarro Cabello, E. (2018). Kinematics of recreational runners with iliotibial band injury. *Journal of Human Sport and Exercise*, 13(3), 698-709. doi:<https://doi.org/10.14198/jhse.2018.133.19>



Corresponding author. *Health and human performance departament. Faculty of Sports Sciences. Technical University of Madrid. Madrid. Spain.*

E-mail: bruno.suarez.luginick@alumnos.upm.es

Submitted for publication April 2018

Accepted for publication May 2018

Published *in press* May 2018

JOURNAL OF HUMAN SPORT & EXERCISE ISSN 1988-5202

© Faculty of Education. University of Alicante

doi:10.14198/jhse.2018.133.19

INTRODUCTION

Running has unquestionable benefits on health. However, it entails some risks, with the incidence of injury ranging from 19.4% to 79.3% (Van Gent et al., 2007, Linde, 1986, Daoud, et al., 2012, Bovens et al. 1989). The most commonly injured joint on runners is the knee (Fields, 2011; Bovens et al., 1989; Taunton et al, 2002;). According to Kezunovic (2013), 45% of all overuse knee injuries are caused by running.

Iliotibial band syndrome (ITBS) is the second most common cause of knee pain in runners (Van der Worp, Van der Horst, De Wijer, Backx & Nijhuis-van der Sanden, 2012; Taunton et al., 2002). As reported by Taunton et al (2012), women are twice as likely to develop ITBS as men. According to Phinyomark, Osis, Hettinga, Leigh, & Ferber (2015), gender should be considered in the treatment of ITBS. Based on a study in female runners with a history of ITBS, Ferber, Noehren, Hamill, & Davis, (2010) attributed a greater strain on the iliotibial band (ITB) in female runners due to their greater peak hip adduction angle and knee internal rotation angle.

The ITB is a thick band of fascia formed by connective tissue, a strong tendinous continuation of the tensor fasciae latae and gluteus maximus muscles. The iliotibial band provides stabilization of the hip and knee, limiting hip adduction and knee internal rotation in all planes of motion (Fredericson et al., 2000 and Clemente, 2008). In relation to the knee, the ITB supports the fibular collateral ligament for the transverse stability of the knee.

Lindenberg, Pinshaw & Noakes (1984) and Noble (1980) reported that, pain at the injury site occurs when friction from the band rubbing over the bony prominence of the lateral femoral condyle causes an inflammatory response in the ITB, the periosteum of the underlying bone, and/or the bursa that lies between the bony prominence and the fascia. In contrast, Fairclough et al. (2006) reported that pain can also originate from increased compression over the richly innervated fat tissue deep beneath the ITB but superficial to the epicondyle. Orchard, Fricker, Abud, & Mason, (1996) reported that friction between the ITB and the condyle occurs at 20° to 30° of knee flexion during the first half of the stance phase of running ("Sagittal plane theory"). Yet, no differences in knee flexion and extension patterns have been found between ITBS runners and healthy controls (Miller, Lower, Meardon, & Gillette 2007; and Noehren, Davis, & Hamill 2007).

The causes of ITBS are not well understood, and differences in the kinematics of ITBS runners as compared to unaffected runners have not been conclusively identified. Motions in other planes and joints may contribute to ITBS (Phinyomark et al., 2015). Other potential factors such as excessive hip adduction (Noehren et al., 2007), excessive knee internal rotation (Noehren et al., 2007; Fairclough et al., 2006; Grau, Maiwald, Krauss, Axmann & Horstmann, 2008; Miller et al., 2007 & Phinyomark et al., 2015), hip external rotation (Phinyomark et al. 2015; Tateuchi, Shiratori & Ichihashi, 2015; Baker, Souza, & Fredericson et al., 2000), rear-foot eversion (Noehren et al., 2007; Ferber et al. 2010; Hamill, Van Emmerik, Heiderscheit, & Li, 1999) and maximum foot inversion (Miller et al., 2007) may also contribute to ITBS. The only known kinetic abnormality is decreased maximum normalized braking force (Messier et al., 1995).

The biomechanical etiology of ITBS remains unclear, a variety of biomechanical factors are associated with a higher risk for ITBS. The first purpose of this study was to assess potential differences in the running technique employed by runners with current ITBS and healthy runners. Based on the literature and the prospective study by Noehren et al. 2007, we hypothesized that runners with ITBS would exhibit significantly greater frontal, sagittal and transverse plane hip, knee, ankle joint angles during the stance phase of running. The second purpose of this study was to examine how ITBS affects running kinematics in male and female

runners experiencing ITBS. Based on the retrospective study by Foch & Milner, (2014), we hypothesized that male and female runners with ITBS have different kinematic profiles.

MATERIALS AND METHODS

Participants

Sample size was determined *a priori* ($\alpha = 0.05$, $b = 0.20$, desired effect size = 0.8) for one-way analysis of variance (ANOVA) using the power analysis program G*Power 3 (Faul, Erdfelder, Lang, & Buchner, 2007). The effect size chosen is based on differences reported in a prospective ITBS study (Noehren et al., 2007). Power analysis revealed that a minimum sample of 28 participants was needed. Sixty recreational runners were recruited, exceeding the minimum estimated sample size. Participants were classified into four groups: a group of male runners with ITBS (M); a group of female runners with ITBS (F); a group of male controls CO (M); and a group of female controls CO (F) (Table 1). All runners in the sample had been running a minimum of 20km per week for more than two years. As the kinematic rollover pattern of forefoot runners (forefoot-heel-forefoot) differs from that of rearfoot runners (heel-forefoot) and the running study affects distinct time-dependent and joint coordination parameters, only rearfoot runners were included in the ITBS group.

Inclusion criteria for current ITBS:

- ITBS as diagnosed by a health professional (sports doctor, traumatologist, or licensed physiotherapist).
- Appearance of the typical pattern of symptoms while running (i.e. absence of pain at start, onset of pain during the run, remission of pain after a period of rest or referred pain some hours after the run.)
- Referred pain in the lateral femoral condyle associated with physical exercise at the moment of the study.
- Absence of concomitant injuries in the same anatomical region (lateral meniscus injury, chronic tendonitis of the collateral lateral ligament, popliteus tendon syndrome, among others) reported in medical record.
- Male and female subjects 18 to 55 years of age.
- A weekly run distance of at least 20 km.

Inclusion criteria for controls (CO):

- Not having ever experienced any pain in the lateral femoral condyle while running.
- Runners without a history of knee injury caused by running.
- Male and female subjects 18 to 55 years of age.
- A weekly run distance of at least 20 km.

Informed consent was obtained from all subjects. The study was approved by the local Ethics Committee and in accordance with the Declaration of Helsinki as amended at the 59th General Assembly held in Seoul in October 2008, the Spanish Act 14/2007 of July 3rd on Biomedical Research, and the Oviedo Convention on Human Rights and Biomedicine (1997). At the time of data collection, none of the subjects in the ITBS group were handicapped by pain, as the onset of pain in ITBS typically occurs after a “reproducible time or distance run” (Fredericson et al., 2000), and not from the very beginning of a run or at rest.

Table 1. Age, height, weight for the IBFS groups as compared to controls.

	M ITBS	M Control	F ITBS	F Control
n	15	15	15	15
Age (y)	36.6 (8.76)	38.4 (10.62)	40.6 (7.61)	41.47 (7.96)
Height (m)	1.76 (.05)	1.76 (.05)	1.61 (.05)	1.63 (.06)
Weight (kg)	76.59 (8.78)	72.33 (5.46)	55.43 (6.3)	54.41 (2.97)
Speed (m/s)	3.04 (0.43)	3.11 (0.28)	2.74 (0.44)	2.66 (0.31)

* Values are mean (SD)

* Speed during the test

Measures

Subjects were asked to run in their usual running shoes on a 5 x 15m flat track marked with traffic cones. A clear description of the route to be completed was provided. Runners run at a self-selected pace (Table 1) until four trials were completed for each leg, in which runners moved over the force plates. Measurement methods were not explained to runners to prevent alterations in their running technique. Standardized 10-minute warm-up was performed in the same circuit.

The running technique of all subjects was analyzed using a system of six infrared Vicon® cameras (Oxford Metrics Ltd, United Kingdom) set at a frequency of 120 Hz and synchronized with two Kistler® force plates (Kistler Group, Switzerland) at 1000Hz.

Procedures

The body was defined as a set of seven rigid solid segments articulated together: pelvis and both thighs, legs, and feet, respectively. For the determination of the six degrees of freedom of movement for each segment, 23 spherical (14 mm in diameter) motion capture reflective markers were fixed on the body using 3M HealthCare tape. Four markers were placed on the hip (on the upper border of the right, left, anterior, and posterior iliac crests), one on each trochanter of the femur, two on each knee (medial condyle and fibular head), one on the outer thigh, one on the outer leg, two on each ankle (lateral and medial malleolus), and three on each foot of the running shoe (on the head of the second toe, on the calcaneus at the same level as the previous one, and on the head of the fifth metatarsal). Measurements were made by static and dynamic testing –where markers on the medial knee, ankle, and trochanter were removed for greater runner comfort. Therefore, dynamic analysis included a total of 18 markers.

3-D coordinates of the markers were filtered and interpolated using fifth-order splines following the procedure developed by Woltring, which was implemented using the Vicon® Workstation program. For the determination of the smoothing factor, the mean square error (MSE) method was used, considering 4 mm² as the standard deviation of data. Once the 3D coordinates of the markers were recorded, the following dependent variables were obtained: frequency (number of cyclical leg movements per minute), and amplitude (distance covered by each leg between its two extreme positions); along with hip, knee, and ankle angle with respect to the three anatomical axes (transverse, anterior-posterior, and longitudinal), and ground reaction forces by injury status (injured versus non-injured). All calculations were performed using VICON BodyBuilder software (VICON; Oxford Metrics Ltd., United Kingdom).



Figure 1. Outline of markers.

Analysis

Comparisons among the four groups were performed using SPSS 20.0 (SPSS Inc., Chicago, IL, USA). First, two-factor ANOVA was calculated: injury (2) x leg-repeated measures (2) for men and women to assess potential kinematic differences in the legs of runners. Two-factor ANCOVA of injury (2) x gender (2) was conducted to determine whether there were significant differences between (male and female) injured runners and controls. Speed was selected as covariate. The Bonferroni correction was used to prevent experimental error from multiple comparisons. Results are grouped by related hypothesis. A $p < 0.05$ was considered statistically significant. Effect size was calculated using eta squared for each group of variables (temporospatial, sagittal, frontal and transverse planes of motion and ground reaction forces). Cohen's d was used to determine effect sizes across variables. Based on Cohen's conventional criteria (Cohen, 1988), an effect size (d) greater than 0.8 was considered large, whereas an effect size between 0.5 and 0.8 was considered medium (namely a trend).

RESULTS

Preliminary analysis revealed that no significant differences exist between the right and left leg of controls ($p > 0.05$). The left leg was selected as the element of study. No differences were observed either between the injured leg and the non-injured leg of runners with ITBS ($p > 0.05$), which is consistent with the literature (Orchard, 1996).

The effects of the factor "injury" on the temporospatial variables were non-significant ($F_{11}=1.913$, $p=0.063$). In contrast, significant gender-based differences were found ($F_{11}=5.983$, $p<0.001$, $ES=0.59$). The effect of injury and gender interaction was significant ($F_{11}=2.372$, $p=0.021$, $ES=0.37$).

Differences were observed among variables (Table 2). The runners with ITBS (male and female) exhibited shorter contact time, with a moderate effect ($d=0.55$). Contact time was shorter in the F (ITBS) group ($d=0.90$) as compared to F (CO).

Table 2. Parameters of running for the different groups (means \pm SD).

	M ITBS (15)	M Control (15)	F ITBS (15)	F Control (15)	ITBS (30)	Control (30)
Amplitude (m) ¹	2.21 (0.28)	2.32 (0.22)	1.97 (0.32)	1.92 (0.21)	2.09 (0.32)	2.12 (0.29)
Frequency (Cycle/min)	1.374 (0.05)	1.342 (0.05)	1.399 (0.04)	1.390 (0.06)	1.387 (0.04)	1.366 (0.06)
Contact time (s) ^{2,3}	0.273 (0.03)	0.278 (0.03)	0.263 (0.02)	0.286 (0.03)	0.268 (0.02)	0.282 (0.03)
Norm. amplitude	1.25 (0.14)	1.32 (0.10)	1.22 (0.21)	1.18 (0.13)	1.24 (0.17)	1.25 (0.14)
Norm. contact time (%) ²	37.34 (4.13)	36.76 (4.06)	36.8 (3.28)	39.67 (4.03)	37.07 (3.68)	38.21 (4.24)

* Values are mean (SD)

1: significant differences in the M ITBS and M Control

2: significant differences in the F ITBS and F Control

3: significant differences in ITBS and Control

The effects of the factor "injury" on sagittal plane variables were not significant ($F_{23}=1.427$, $p=0.172$). Significant gender-based differences were observed ($F_{23}=2.446$, $p<0.009$, $ES=0.63$). The effect of injury and gender interaction was not significant ($F_{23}=0.824$, $p=0.682$).

Significant differences in movements in the sagittal plane are displayed in Table 3. The (male and female) ITBS group exhibited greater anteversion of the pelvis (both, maximum and minimum angle), with very significant differences ($d=.83$ and $d=1.29$). Knee flexion angle at initial contact and knee peak flexion during stance were smaller in the ITBS group ($d=0.66$ and 1.28 , respectively). These effects manifested differently in male and female runners. Anteversion of the pelvis was greater in M (ITBS), with a small effect ($d=0.31$). Peak knee flexion angle was smaller during stance ($d=0.22$) and swing ($d=0.52$), yet effects were small and medium, respectively. Knee flexion at initial contact was decreased in F (ITBS), with a medium effect ($d=0.71$). No significant differences were observed in ankle motion.

The effect of the factor "injury" on frontal plane variables revealed as significant ($F_{14}=6.361$, $p<0.001$, $ES=0.68$) and significant gender-based differences were observed ($F_{14}=6.536$, $p<0.001$, $ES=0.68$). The effect of injury-gender interaction was also significant ($F_{14}=2.250$, $p=0.022$, $ES=0.42$). The differences observed are displayed in Table 4. Peak knee varus angle was smaller in ITBS runners (male and female), with a very large effect ($d=1.09$). It is remarkable that peak knee valgus angle was decreased both in men and women, although its effect was very large in men ($d=1.53$) and moderate in women ($d=0.7$). Adduction at toe-off was reduced in female ITBS runners, with a very large effect ($d=1.11$). There were no significant differences in the kinematics of the foot.

In relation to the main effects of injury on sagittal transverse variables, the effect of the factor "injury" was significant ($F_7=5.288$, $p<0.001$, $ES=0.43$). Significant gender-based differences were observed ($F_7=3.951$, $p=0.002$, $ES=0.36$). The effect of injury-gender interaction was not significant ($F_7=1.793$, $p=0.11$).

The differences observed are displayed in Table 5. Hip internal rotation in ITBS runners (male and female) was decreased, with a moderate effect ($d=0.65$).

Table 3. Angles in the sagittal plane (means \pm SD)

	M ITBS (15)	M Control (15)	F ITBS (15)	F Control (15)	ITBS (30)	Control (30)
Minimum anteversion of the pelvis (°) 1,3	13.81 (4.51)	10.25 (4.11)	14.80 (4.40)	13.52 (3.93)	14.30 (4.41)	11.89 (4.28)
Maximum anteversion of the pelvis. (°) 1,3	21.72 (3.81)	16.78 (3.82)	23.51 (4.18)	21.88 (5.29)	22.62 (4.03)	19.33 (5.22)
Peak hip extension at toe-off (°)	-3.91 (6.34)	-7.36 (5.50)	-4.92 (6.67)	-2.81 (2.89)	-4.42 (6.42)	-5.08 (4.89)
Peak hip flexion during swing (°)	50.05 (7.97)	50.42 (7.04)	53.87 (6.74)	52.15 (5.10)	51.96 (7.51)	51.29 (6.10)
Knee flexion at initial contact (°) _{2,3}	16.46 (4.21)	19.28 (4.31)	13.48 (5.04)	17.17 (4.24)	14.97 (4.81)	18.22 (4.34)
Peak knee flexion at during stance (°) 1,3	44.53 (3.58)	49.42 (4.22)	45.41 (5.40)	46.55 (5.17)	44.97 (4.52)	47.99 (4.86)
Peak knee flexion during swing (°) 1	95.76 (13.06)	104.39 (12.36)	99.32(15.00)	93.11(8.03)	97.54(13.94)	98.75 (11.7)
Ankle flexion at initial contact (°)	6.59 (4.75)	8.37 (7.49)	10.40 (3.88)	9.31 (4.80)	8.49 (4.68)	8.84 (6.20)
Maximum ankle flexion at during stance (°)	24.84 (3.45)	27.05 (3.78)	24.73 (3.75)	25.12 (3.24)	24.79 (3.54)	26.09 (3.60)
Minimum ankle flexion at toe-off (°)	-22.27 (4.00)	-23.71 (6.18)	-26.62 (7.51)	-24.53 (7.18)	-24.45 (6.31)	-24.12(6.60)
Foot-ground angle at initial contact (°)	10.34 (6.88)	15.10 (10.34)	14.35 (4.12)	15.40 (4.75)	12.34 (5.93)	15.25 (7.91)

* Values are mean (SD)

1: significant differences in the M ITBS and M Control

2: significant differences in the F ITBS and F Control

3: significant differences in ITBS and Control

Table 4. Angles in the frontal plane (means \pm SD)

	M ITBS (15)	M Control (15)	F ITBS (15)	F Control (15)	ITBS (30)	Control (30)
Peak hip adduction at initial contact (°)	4.76 (3.30)	5.14 (3.42)	7.06 (3.82)	8.21 (3.21)	5.91 (3.70)	6.68 (3.61)
Peak hip adduction at during stance (°)	11.37 (2.55)	12.00(3.74)	13.84(3.76)	13.84 (2.71)	16.6 (3.40)	12.92(3.34)
Peak hip adduction at toe-off (°) ₂	-2.28 (5.09)	-2.74(3.51)	-5.65 (2.7)	-2.58 (2.81)	-3.97(4.35)	-2.66 (3.13)
Minimum varus angle (°) _{1,3}	-2.29 (3.99)	-9.86(5.77)	-6.12(4.97)	-9.51 (4.68)	-4.21(4.84)	-9.68 (5.16)
Supination at during stance (°)	6.09 (6.02)	8.68 (8.55)	4.10 (5.78)	6.30 (9.27)	5.10 (5.89)	7.49 (8.84)
Maximum pronation at during stance (°)	-9.76 (4.78)	-10.3(7.34)	-12.27(4.8)	-9.42 (6.62)	-11.01(4.8)	-9.89 (6.88)

* Values are mean (SD)

1: significant differences in the M ITBS and M Control

2: significant differences in the F ITBS and F Control

3: significant differences in ITBS and Control

The effects of the factor "injury" on reaction forces were not significant ($F_6=1.913$, $p=0.20$). Yet, significant gender-based differences were observed ($F_6=20.488$, $p<0.001$, $ES=0.71$). The effect of injury-gender interaction was not significant ($F_6=1.617$, $p=0.16$).

Table 5. Angles in the transverse plane (means \pm SD)

	M ITBS (15)	M Control (15)	F ITBS (15)	F Control (15)	ITBS (30)	Control (30)
Hip rotation at initial contact (°)	-4.38 (5.58)	-4.56 (9.78)	-6.93(8.23)	-8.73 (8.53)	-5.66 (7.03)	-6.65 (9.26)
Peak hip rotation (°) 3	5.22 (4.65)	5.21 (10.4)	2.31 (9.96)	4.22 (7.10)	3.77 (7.78)	9.71 (10.38)
Knee rotation at initial contact (°)	-17.35(10.5)	-21.81(8.47)	-11.23(6.6)	-13.49(10.8)	-14.29(9.22)	-17.65(10.4)
Peak knee rotation at during stance (°)	5.45 (10.35)	3.98 (8.45)	10.94(7.50)	10.12 (9.23)	8.18 (9.32)	7.05 (9.24)

* Values are mean (SD)

1: significant differences in the M ITBS and M Control

2: significant differences in the F ITBS and F Control

3: significant differences in ITBS and Control

The differences found are displayed in Table 6. Female ITBS runners exhibited greater peak positive anterior-posterior force, with a large effect ($d=1.0$), and a greater peak vertical ground-reaction force, with a medium effect ($d=0.71$).

Table 6. Ground-reaction forces (means \pm SD).

	M ITBS (15)	M Control (15)	F ITBS (15)	F Control (15)	ITBS (30)	Control (30)
Norm. F antero-posterior (N/W)	-0.33 (0.02)	-0.34 (0.04)	-0.33 (0.07)	-0.30 (0.06)	-0.33(0.06)	-0.32 (0.06)
Norm. F medial-lateral (N/W) 2	0.27 (0.06)	0.29 (0.05)	0.27 (0.05)	0.22 (0.05)	0.27 (0.05)	0.25 (0.06)
Norm. F vertical (N/W) 2	2.54 (0.29)	2.50 (0.24)	2.45 (0.32)	2.17 (0.46)	2.49(0.30)	2.33 (0.40)

* Values are mean (SD)

1: significant differences in the M ITBS and M Control

2: significant differences in the F ITBS and F Control

3: significant differences in ITBS and Control

DISCUSSION

The purpose of this retrospective study was to investigate whether differences exist in the biomechanics of running between male and female runners with current ITBS and controls without a history of knee injury caused by running. After a thorough literature review, we decided to assess joint biomechanics in the three planes of motion, namely: the sagittal, frontal and transverse plane. An analysis of temporospatial variables and ground contact forces was also performed. It is worth mentioning that the studies conducted so far primarily included female runners with a history of ITBS or runners who developed ITBS during follow-up. In contrast, we analyzed how the presence of a *current* injury (ITBS) affects the biomechanics of running.

Significant differences were observed in the temporospatial variables amplitude and contact time. Contact time was shorter in the ITBS group (male and women), as compared to the CO group. This is consistent with the results obtained by Lieberman et al. (2010), who relates greater velocity of impact and decreased capacity of absorption with greater loading on the knee. In addition, amplitude showed to be significantly greater in the ITBS group. Although amplitude is considered crucial to improving running technique (Hay, J. G., & Reid, J. G., 1988), there is no published data on amplitude in runners with ITBS. It is worth mentioning that gender-based differences were observed in significant variables. Significant gender-based differences were found in relation to contact time, which was lower in female ITBS runners.

As to the sagittal plane, there were significant differences in anteversion of the pelvis, knee flexion at initial contact and peak during stance. Differences were also observed in maximum knee flexion angle, which was smaller in the ITBS group (male and female) as compared to the CO group. The results obtained provide further evidence of the relevant role that knee flexion angle plays in the etiology of ITBS, as previously reported (Noble, 1980; Orchard, Fricker, Abud, & Mason, 1996). Differences were found in maximum and minimum anteversion of the pelvis between the ITBS group and controls. The values obtained might be associated with excessive strain on the iliotibial band and the muscles attached to it (i.e. gluteus maximus and tensor fasciae latae). Significant gender-based differences were noted. In men, differences were recorded in pelvis anteversion angle and knee flexion angle during the stance phase and swing. In women, the only significant difference shown was in knee flexion angle at initial contact. No differences were observed between groups in hip and ankle flexion and extension angle. These results are in line with those obtained by Phinyomark et al., (2015), who studied a sample of 48 runners with current ITBS.

In relation to motions in the frontal plane, no differences were demonstrated in hip adduction angle between ITBS runners and controls. However, excessive hip adduction has been identified as a risk factor for ITBS (Noehren et al., 2007; Ferber et al., 2010; Tateuchi et al., 2015; MacMahon, Chaudhari, & Andriacchi, 2000). Nevertheless, it should be noted that the subjects included in these studies had a history of ITBS or developed ITBS subsequently during follow-up but did not have *current* ITBS during the study. The similar hip adduction angle observed in the runners of our study might be related to the greater trunk ipsilateral flexion exhibited by runners with current ITBS and/or an increased rigidity of tissue caused by the injury, which limits hip adduction (Foch, Reinbolt, Zhang, Fitzhugh y Milner, 2015).

Knee valgus angle was greater in runners with current ITBS and controls. This result supports the evidence provided by Taunton et al (2002) that increased valgus might be associated with weakness in the adductor muscles of the hip.

No differences were seen between groups in rear-foot eversion, which contradicts the results obtained by McClay & Manal (1998); Nawoczenski, Saltzman, & Cook (1998). This inconsistency might be due to the methodology employed, as tests in these studies were performed on a treadmill, whereas, in our study, running was performed on the ground.

Regarding movements in the transverse plane, authors associate excessive tibial internal rotation with ITBS (Noehren et al. 2007; Fairclough et al. 2006; Grau et al. 2008; Miller et al. 2007 and Phinyomark et al. 2015), which was not confirmed by the results of our study or the Foch et al. study (2015). It is worth noting that the samples of the studies that demonstrated a correlation between excessive tibial internal rotation and ITBS were exclusively composed of female runners. Additionally, methodologies were not homogeneous, namely: Noehren et al. (2007) included a study with a sample of female runners who developed ITBS during follow-up. Fairclough et al. (2006) developed a cadaveric study. Finally, Miller et al. (2007) conducted a study on exhaustive running on a treadmill, as did Phinyomark et al (2015). In our study, significant differences were only found in hip internal rotation, which was smaller in the current-ITBS group, which is not in agreement with the results obtained by Phinyomark et al. (2015). As it was mentioned above, this difference might be due to methodological inconsistencies across studies.

Regarding ground reaction forces, there were no differences between ITBS groups (male and female) and controls. In contrast, significant differences were observed in female runners regarding peak anterior-posterior force and peak vertical force. These results might be supported by authors such as Lieberman et

a. (2010), who associate a greater velocity of impact and decreased capacity of absorption with a greater loading on the knee.

Notably, less than half the differences were statistically significant and none was significant both for the male and female group. This is suggestive of a potential gender-based risk factor for ITBS. The results obtained are in line with those reported by Foch et al. (2015). The reason for such consistency may be that the author clearly distinguished between current ITBS and a history of ITBS, which is demonstrated by this study to be a relevant factor. Our results contradict those obtained in previous studies in subjects with a history of leg injury, a history of ITBS, or based on different measurement methods such as those conducted by Ferber et al. (2010); Foch, E., & Milner, C. E. (2014); Miller et al. (2007); Noehren et al. (2007).

A limitation of this study is that, although participants were diagnosed by a health professional, the current status of the injury was not assessed by a functional test the same day that measurements were performed. Another potential limitation is that running tests took place indoors on a 15-m track at a self-selected pace. Although speed did not have any effect as a covariate, running indoors instead of outdoors may affect the running technique. Finally, the optimal study design to assess an overuse injury is by a prospective study, although a cross-sectional study can yield data related to the specific status of an injury.

CONCLUSIONS

Recreational runners with current ITBS exhibited lower stance time, braking distance, knee flexion and varus angle and hip rotation than controls. No significant differences were documented in tibial internal rotation, hip adduction, and foot eversion, which are associated with female runners with a history of ITBS or who ultimately develop ITBS. ITBS affects men and women differently. These factors should be considered by coaches and physical trainers when modulating the running technique of runners with ITBS.

REFERENCES

- Baker, R. L., Souza, R. B., & Fredericson, M. (2011). Iliotibial band syndrome: soft tissue and biomechanical factors in evaluation and treatment. *PM&R*, 3(6), 550-561. <https://doi.org/10.1016/j.pmri.2011.01.002>
- Bovens, A. M. P., Janssen, G. M. E., Vermeer, H. G. W., Hoeberigs, J. H., Janssen, M. P. E., & Verstappen, F. T. J. (1989). Occurrence of running injuries in adults following a supervised training program. *Int J Sports Med*, 10(S 3), S186-S190. <https://doi.org/10.1055/s-2007-1024970>
- Clemente, C. D. (2008). Clinically oriented anatomy. *JAMA*, 299(2), 220-226. <https://doi.org/10.1001/jama.2007.14>
- Daoud A.I., Geissler G. J., Wang F., Saretsky J., Daoud Y. A., Lieberman D. E. (2012) Foot Strike and Injury Rates in Endurance Runners: A Retrospective Study. *Med Sci Sport Exer.* <https://doi.org/10.1249/MSS.0b013e3182465115>
- Fairclough, J., Hayashi, K., Toumi, H., Lyons, K., Bydder, G., Phillips, N., & Benjamin, M. (2006). The functional anatomy of the iliotibial band during flexion and extension of the knee: implications for understanding iliotibial band syndrome. *J Anat*, 208(3), 309-316. <https://doi.org/10.1111/j.1469-7580.2006.00531.x>
- Faul F, Erdfelder E, Lang AG, Buchner A. (2007). G*Power 3: a flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behav Res Methods* 2007;39(2):175–91. <https://doi.org/10.3758/BF03193146>

- Ferber, R., Noehren, B., Hamill, J., & Davis, I. (2010). Competitive female runners with a history of iliotibial band syndrome demonstrate atypical hip and knee kinematics. *J Orthop Sport Phys*, 40(2), 52-58. <https://doi.org/10.2519/jospt.2010.3028>
- Fields, K. B. (2011). Running injuries-changing trends and demographics. *Curr Sport Med Rep*, 10(5), 299-303. <https://doi.org/10.1249/JSR.0b013e31822d403f>
- Foch, E., Reinbolt, J. A., Zhang, S., Fitzhugh, E. C., & Milner, C. E. (2015). Associations between iliotibial band injury status and running biomechanics in women. *Gait Posture*, 41(2), 706-710. <https://doi.org/10.1016/j.gaitpost.2015.01.031>
- Foch, E., & Milner, C. E. (2014). The influence of iliotibial band syndrome history on running biomechanics examined via principal components analysis. *J Biomech*, 47(1), 81-86. <https://doi.org/10.1016/j.jbiomech.2013.10.008>
- Foch, E., & Milner, C. E. (2014). Frontal plane running biomechanics in female runners with previous iliotibial band syndrome. *J Appl Biomech*, 30(1), 58-65. <https://doi.org/10.1123/jab.2013-0051>
- Fredericson, M., Cookingham, C. L., Chaudhari, A. M., Dowdell, B. C., Oestreicher, N., & Sahrmann, S. A. (2000). Hip abductor weakness in distance runners with iliotibial band syndrome. *Clin J Sport Med*, 10(3), 169-175. <https://doi.org/10.1097/00042752-200007000-00004>
- Grau, S., Maiwald, C., Krauss, I., Axmann, D., & Horstmann, T. (2008). The influence of matching populations on kinematic and kinetic variables in runners with iliotibial band syndrome. *Res Q Exercise Sport*, 79(4), 450-457. <https://doi.org/10.1080/02701367.2008.10599511>
- Hamill, J., van Emmerik, R. E., Heiderscheit, B. C., & Li, L. (1999). A dynamical systems approach to lower extremity running injuries. *Clin Biomech*, 14(5), 297-308. [https://doi.org/10.1016/S0268-0033\(98\)90092-4](https://doi.org/10.1016/S0268-0033(98)90092-4)
- Hay, J. G., & Reid, J. G. (1988). *Anatomy, mechanics, and human motion*. Prentice Hall.
- Kezunovic, M. (2013). Overuse Knee Injuries in Athletes. *Montenegrin Journal of Sports Science and Medicine*, 2(1), 29-32.
- Lieberman, D. E., Venkadesan, M., Werbel, W. A., Daoud, A. I., D'Andrea, S., Davis, I. S., & Pitsiladis, Y. (2010). Foot strike patterns and collision forces in habitually barefoot versus shod runners. *Nature*, 463(7280), 531-535. <https://doi.org/10.1038/nature08723>
- Linde F., MD . Injuries in Orienteering. (1986). *Brit J Sport Med* - Vol. 20, No. 3, September 1986, pp. 125-127. <https://doi.org/10.1136/bjism.20.3.125>
- Lindenberg, G., Pinshaw, R., & Noakes, T. D. (1984). Iliotibial band friction syndrome in runners. *The Physician and Sports medicine*, 12(5), 118-130. <https://doi.org/10.1080/00913847.1984.11701850>
- MacMahon, J. M., Chaudhari, A. M., & Andriacchi, T. P. (2000). Biomechanical injury predictors for marathon runners: striding towards iliotibial band syndrome injury prevention. In *ISBS-Conference Proceedings Archive* (Vol. 1, No. 1).
- McClay, I., & Manal, K. (1998). A comparison of three-dimensional lower extremity kinematics during running between excessive pronators and normals. *Clin Biomech*, 13(3), 195-203. [https://doi.org/10.1016/S0268-0033\(97\)00029-6](https://doi.org/10.1016/S0268-0033(97)00029-6)
- Miller, R. H., Lower J. L., Meardon, S. A., & Gillette, J. C. (2007). Lower extremity mechanics of iliotibial band syndrome during an exhaustive run. *Gait Posture*, 26(3), 407-413. <https://doi.org/10.1016/j.gaitpost.2006.10.007>
- Nawoczenski, D. A., Saltzman, C. L., & Cook, T. M. (1998). The effect of foot structure on the three-dimensional kinematic coupling behavior of the leg and rear foot. *Phys Ther*, 78(4), 404. <https://doi.org/10.1093/ptj/78.4.404>
- Noble, C. A. (1980). Iliotibial band friction syndrome in runners. *Am J Sport Med*, 8(4), 232-234. <https://doi.org/10.1177/036354658000800403>

- Noehren, B., Davis, I., & Hamill, J. (2007). ASB Clinical Biomechanics Award Winner 2006: Prospective study of the biomechanical factors associated with iliotibial band syndrome. *Clin Biomech*, 22(9), 951-956. <https://doi.org/10.1016/j.clinbiomech.2007.07.001>
- Orchard, J. W., Fricker, P. A., Abud, A. T., & Mason, B. R. (1996). Biomechanics of iliotibial band friction syndrome in runners. *Am J Sport Med*, 24(3), 375-379. <https://doi.org/10.1177/036354659602400321>
- Phinyomark, A., Osis, S., Hettinga, B. A., Leigh, R., & Ferber, R. (2015). Gender differences in gait kinematics in runners with iliotibial band syndrome. *Scan J Med Sci Sport* 25(6), 744-753. <https://doi.org/10.1111/sms.12394>
- Taunton, J. E., Ryan, M. B., Clement, D. B., McKenzie, D. C., Lloyd-Smith, D. R., & Zumbo, B. D. (2002). A retrospective case-control analysis of 2002 running injuries. *Br J Sports Med*, 36(2), 95-101. <https://doi.org/10.1136/bjism.36.2.95>
- Tateuchi, H., Shiratori, S., & Ichihashi, N. (2015). The effect of angle and moment of the hip and knee joint on iliotibial band hardness. *Gait Posture*, 41(2), 522-528. <https://doi.org/10.1016/j.gaitpost.2014.12.006>
- Van der Worp, M. P., van der Horst, N., de Wijer, A., Backx, F. J., & Nijhuis-van der Sanden, M. W. (2012). Iliotibial band syndrome in runners. *Sport Med*, 42(11), 969-992. <https://doi.org/10.1007/BF03262306>
- Van Gent, R. N., Siem D., Middelkoop M. van, van Os A. G., Bierma-Zeinstra S M A, Koes B W. (2007). Incidence and determinants of lower extremity running injuries in long distance runners: a systematic review. *Br J Sports Med* 2007; 41:469–480. <https://doi.org/10.1136/bjism.2006.033548>

