Gait & Posture 41 (2015) 706–710

Contents lists available at ScienceDirect

Gait & Posture

journal homepage: www.elsevier.com/locate/gaitpost

Associations between iliotibial band injury status and running biomechanics in women

Eric Foch [a,*], Jeffrey A. Reinbolt [b], Songning Zhang [a], Eugene C. Fitzhugh [a], Clare E. Milner [a]

[a] Department of Kinesiology, Recreation, and Sports Studies, University of Tennessee, Knoxville, TN, USA
[b] Department of Mechanical, Aerospace, and Biomedical Engineering, University of Tennessee, Knoxville, TN, USA

ARTICLE INFO

Article history:
Received 9 April 2014
Received in revised form 24 January 2015
Accepted 30 January 2015

Keywords:
Trunk lateral flexion
Hip abductor strength
Iliotibial band flexibility
Ober test
Female

ABSTRACT

Iliotibial band syndrome (ITBS) is a common overuse knee injury that is twice as likely to afflict women compared to men. Lower extremity and trunk biomechanics during running, as well as hip abductor strength and iliotibial band flexibility, are factors believed to be associated with ITBS. The purpose of this cross-sectional study was to determine if differences in lower extremity and trunk biomechanics during running exist among runners with current ITBS, previous ITBS, and controls. Additionally, we sought to determine if isometric hip abductor strength and iliotibial band flexibility were different among groups. Twenty-seven female runners participated in the study. Participants were divided into three equal groups: current ITBS, previous ITBS, and controls. Overground running trials, isometric hip abductor strength, and iliotibial band flexibility were recorded for all participants. Discrete joint and segment biomechanics, as well as hip strength and flexibility measures were analyzed using a one-way analysis of variance. Runners with current ITBS exhibited 1.8 (1.5)° greater trunk ipsilateral flexion and 7 (6)° less iliotibial band flexibility compared to runners with previous ITBS and controls. Runners with previous ITBS exhibited 2.2 (2.9)° less hip adduction compared to runners with current ITBS and controls. Hip abductor strength 3.3 (2.6) %BM $\times$ h was less in runners with previous ITBS but not current ITBS compared to controls. Runners with current ITBS may lean their trunk more towards the stance limb which may be associated with decreased iliotibial band flexibility.

1. Introduction

Running is a popular form of exercise for over 32 million Americans [1]. Despite the benefits of weight bearing exercise on the musculoskeletal system [2,3], the likelihood that a runner will sustain a lower extremity injury is indeed high. Previous prospective investigations report an injury incidence ranging from 51% to 85% over six to twenty month periods [4–6]. Similarly, a recent retrospective study found an annual injury incidence rate of 74% in runners [7]. Among injury locations, the knee is the most commonly injured site accounting for 25% to 42% of all reported running injuries [4,8]. Iliotibial band syndrome (ITBS) is second only to patellofemoral pain syndrome (PFPS) as the most common knee overuse injury experienced by runners with women being twice as likely to develop ITBS compared to men [8].

The iliotibial band functions to stabilize the lateral hip and knee, as well as limit hip adduction and knee internal rotation [9]. Excessive hip adduction may increase the tensile strain in the iliotibial band during the stance phase of running [10]. At the knee, excessive knee internal rotation may increase the torsional strain in the iliotibial band [10]. This increased strain may damage the iliotibial band over the period of many runs [11] or compress the highly innervated adipose tissue between the iliotibial band and femoral epicondyle [12], creating pain associated with ITBS.

Contemporary evidence suggests altered frontal and transverse plane hip and knee movement patterns may be associated with the etiology of ITBS. Female runners who later developed ITBS exhibit greater hip adduction and knee internal rotation angles compared to controls [10]. However, the literature remains equivocal in associating greater hip adduction and knee internal rotation angles and previous ITBS in women [13,14]. Excessive hip adduction may place greater eccentric demand on the hip abductor musculature resulting in a greater increased peak hip abductor moment during running. However, the peak hip abductor moment during running was similar between runners who later developed ITBS and runners with previous ITBS compared to controls [10,13]. Additionally, a

* Corresponding author. Department of Nutrition, Exercise, and Health Sciences, Central Washington University, 400 University Way Ellensburg, WA 98926, Tel.: +1 509 963 1912.
E-mail address: foche@cwu.edu (E. Foch).

http://dx.doi.org/10.1016/j.gaitpost.2015.01.031
0966-6362/

large hip adduction angle may be due to hip abductor weakness. Maximal isometric hip abductor strength in ITBS has been investigated previously in mixed gender and male only groups, with inconsistent findings [9,15,16].

In addition to hip and knee motion, altered pelvis and trunk movement patterns may be associated with ITBS. Limited control of the pelvis in the frontal plane may contribute to greater hip adduction. Thus, greater tensile strain may be experienced by the iliotibial band during the stance phase of running with greater contralateral pelvic drop. To limit this, runners with ITBS may lean their trunk more towards the stance limb. Similar to ITBS, there is evidence to suggest hip abductor weakness is associated with PFPS [17,18]. Insight into risk factors for ITBS may be gained by consulting the literature about PFPS in runners. Female runners with current PFPS demonstrated a trend towards trunk ipsilateral flexion [19]. These authors hypothesized that trunk ipsilateral flexion towards the involved limb may be a compensation strategy to reduce the demands on weak hip abductors [19]. Therefore, based on this hypothesis, runners with current ITBS may demonstrate a similar trunk ipsilateral flexion strategy as runners with PFPS.

Although it is unknown whether biomechanics during running are similar before, during, and after the development of ITBS, approximately half of all runners who experienced a running injury reported previous injury to the same anatomical location [20]. Including runners with current ITBS and previous ITBS in a single study would improve upon our understanding of lower extremity and trunk biomechanics during running in relation to injury status. This would assist clinicians to implement evidence informed gait rehabilitation for patients with ITBS. Furthermore, any observed differences in strength or flexibility among runners of different ITBS injury status would aid clinicians to subgroup patients, identifying who may benefit from targeting hip abductor strength or iliotibial band flexibility during rehabilitation. Knowing how ITBS injury status affects biomechanics during running, as well as hip strength and flexibility may aid in the prevention of injury recurrence or occurrence.

Therefore, the purpose of this cross-sectional investigation was to determine if biomechanics during running, as well as hip strength and iliotibial band flexibility differ among female runners with current ITBS, previous ITBS, and controls. It was hypothesized that runners with current ITBS and previous ITBS would exhibit greater peak trunk ipsilateral flexion, contralateral pelvic drop, hip adduction, knee internal rotation, different peak hip abductor moments, and less hip abductor strength and iliotibial band flexibility compared to controls. Additionally, we hypothesized that peak hip adduction during the stance phase of running would be correlated with iliotibial band flexibility and hip abductor strength.

2. Methods

2.1. Participant details

Prior to commencement of this study ethical approval for procedures on human subjects was granted by the University of Tennessee's Internal Review Board. Participants provided informed written consent. All participants were women between the ages of 18 and 45 years. Sample size was determined a priori (α = 0.05, β = 0.20, desired effect size = 0.8) for one-way analysis of variance (ANOVA) using a power analysis program, G*Power 3 [21]. The chosen effect size reflects differences reported in a prospective ITBS study [10]. The results of the power analysis indicated that a minimum sample of twenty-one participants in total were needed. Twenty-seven participants were recruited, exceeding the minimum estimated sample size. Participants were allocated to one of three groups (Table 1): current ITBS, previous ITBS, and controls, according to their injury status. Participants with current ITBS or previous ITBS reported they had been diagnosed by a healthcare professional (physical therapist, physician, or certified athletic trainer). Participants in the previous ITBS group had completed rehabilitation of their injury and had been running without any pain over the lateral knee region for at least one month (median 20 months; range 2–96 months) prior to data collection. Two previously injured participants reported having ITBS more than once. A minimum weekly mileage criterion also had to be met by all participants. Women with previous ITBS and controls were currently running at least 24 km wk^{-1}. Participants with current ITBS were running at least 10 km wk^{-1} [22] and had been experiencing ITBS symptoms, specifically pain over the lateral femoral epicondylar region, during running (median: 12 months; range: 1–84 months). Runners with current ITBS reported the level of lateral knee pain at the end of their past seven runs on a 100 mm visual analog scale (47 (19) mm). Additional exclusion criteria included participants answering 'yes' to any question on the Physical Activity Readiness-Questionnaire (PAR-Q) [23] or reporting a major lower extremity injury.

Table 1
Mean (standard deviation) of participant demographics in the current iliotibial band syndrome (ITBS), previous ITBS, and control groups.

	Current ITBS	Previous ITBS	Controls
Age (years)	26.2 (7.9)	24.7 (5.2)	25.3 (7.0)
Height (m)	1.64 (0.04)	1.68 (0.03)	1.71 (0.05)
Mass (kg)	53.3 (3.7)	61.7 (9.9)	59.6 (5.2)
Weekly distance run (km wk^{-1})	34.8 (23.5)	35.2 (18.7)	45.2 (22.5)

2.2. Experimental protocol

Participants completed a three-dimensional biomechanical analysis of running as described previously [14]. Data were collected on the right side for controls, and on the currently or previously injured lower extremity in the ITBS groups. A nine-camera motion capture system (Vicon, Oxford Metrics, Centennial, CO) sampling at 120 Hz recorded lower extremity, pelvis, and trunk position data. For the running trials, participants ran along a 17 m runway. They were required to run at a velocity within 5% of 3.5 m s^{-1}. A force plate (AMTI, Inc., Watertown, MA) sampling at 1200 Hz located in the middle of the runway was synchronized with the motion capture system. Participants practiced running at the given velocity until they were able to land consistently on the force plate without targeting. Five acceptable trials were collected.

Following the running trials, iliotibial band flexibility and hip strength were measured using established protocols [17,18]. The angles indicated by the inclinometer during the Ober test were averaged among three trials and served as the measure of iliotibial band flexibility. Hip abductor strength was calculated as the average isometric force multiplied by the distance between the greater trochanter to the hand-held dynamometer. A normalized measure of strength was then computed [9]. Hip abductor strength was the average peak isometric hip abductor torque among the three trials. Ten participants were invited back to the laboratory on a separate day to repeat the iliotibial band flexibility and hip abductor strength tests to assess intra-rater variability of a single tester via 95% limits of agreement. Limits of agreement for the iliotibial band flexibility test were $-1.4°$ to $5.4°$. Limits of agreement for the hip abductor strength test were -0.3%body mass × height (BM × h) to 5.4%BM × h. For this test, a bias of 2.6%BM × h and random error of 2.8%BM × h were found.

2.3. Data processing

Running data were processed using custom and commercial software. Data were processed in Visual3D (C-Motion, Rockville,

Table 2
Mean (standard deviation) of peak joint and segment biomechanics during the stance phase of overground running in runners with current iliotibial band syndrome (ITBS), previous ITBS, and controls. Moment is expressed as internal moment. *P* value indicates the main effect of group.

	Current ITBS	Previous ITBS	Controls	*P* value
Trunk ipsilateral flexion (°)	5.6 (1.5)$^{\alpha,\beta}$	3.8 (1.5)$^{\alpha}$	3.3 (1.6)$^{\beta}$	0.011
Contralateral pelvic drop (°)	−6.7 (2.8)	−4.8 (3.3)	−6.1 (1.7)	0.332
Hip abductor moment (N m·(kg m)$^{-1}$)	−1.2 (0.2)	−1.2 (0.2)	−1.3 (0.2)	0.278
Hip adduction angle (°)	16.6 (2.5)$^{\alpha}$	13.4 (3.2)$^{\alpha,\beta}$	16.6 (1.9)$^{\beta}$	0.020
Knee internal rotation (°)	3.9 (6.4)	5.9 (6.4)	3.2 (5.4)	0.598

$^{\alpha,\beta}$ Significant difference between the two groups indicated.

MD). The kinematic and ground reaction force data were low-pass filtered at 8 Hz using 4th order Butterworth filters [24]. The standing calibration trial was used to determine the segment coordinate axes. Joint angles were determined using a six degree-of-freedom approach and a Cardan *X–Y–Z* (mediolateral, anteroposterior, vertical) rotation sequence with respect to the local coordinate system [25]. Segment angles were computed with respect to the global coordinate system. All moments were computed as internal moments and normalized by body mass and height. Joint angle and moment data were expressed in the joint coordinate system. Variables of interest from the running trials were peak: trunk ipsilateral flexion, contralateral pelvic drop, hip abductor moment, hip adduction angle, and knee internal rotation.

2.4. Statistical analysis

The mean of the five trials was determined for every dependent variable for each participant. The dependent variables were compared among groups using an ANOVA with group as the factor. Post hoc Fisher's least significant difference test was used to determine differences among groups when a main effect was found. Pearson correlation coefficients were computed to determine any relationships between peak hip adduction angle and iliotibial band flexibility or hip abductor strength. Statistical analyses were performed using PASW 20.0 (IBM SPSS Statistics, Chicago, IL). An alpha level of 0.05 was set for all statistical tests.

3. Results

Peak trunk ipsilateral flexion was different among runners with current ITBS, previous ITBS, and controls (Table 2). Post hoc tests indicated that runners with current ITBS exhibited greater trunk ipsilateral flexion compared to runners with previous ITBS ($P = 0.023$) and controls ($P = 0.004$) (Fig. 1a). Trunk ipsilateral flexion was similar between runners with previous ITBS and controls ($P = 0.464$). Hip adduction angle was also different among groups (Fig. 1b). Post hoc tests revealed runners with previous ITBS exhibited less hip adduction compared to runners with current ITBS ($P = 0.013$) and controls ($P = 0.016$). Lastly, peak contralateral pelvic drop, hip abductor moment, and knee internal rotation were similar among groups.

Hip abductor strength was different among groups ($P = 0.023$). Post hoc tests revealed that runners with current ITBS exhibited similar isometric hip abductor strength compared to controls (current ITBS: 6.9 (1.6) %BM × *h*; controls: 8.6 (3.4) %BM × *h*; $P = 0.124$). However, runners with previous ITBS exhibited less hip abductor strength (5.3 (1.7) %BM × *h*) than controls ($P = 0.007$). Hip abductor strength was similar between runners with current ITBS and previous ITBS ($P = 0.181$). Lastly, there was no statistically significant correlation between isometric hip abductor strength and peak hip adduction angle ($r = 0.233$; $P = 0.242$).

Iliotibial band flexibility was different among groups ($P = 0.004$). Runners with current ITBS demonstrated less iliotibial band flexibility than runners with previous ITBS (current ITBS: 15 (6) °; previous ITBS: 22 (6) °; $P = 0.003$) and controls (controls: 22 (3) °; $P = 0.003$). Additionally, runners with previous ITBS and controls were similar in iliotibial band flexibility ($P > 0.999$). There was no statistically significant correlation between iliotibial band flexibility and peak hip adduction angle ($r = -0.059$; $P = 0.772$).

4. Discussion

Past ITBS investigations have only measured single biomechanical factors in female runners who either later developed ITBS or had ITBS previously. A more comprehensive examination of how ITBS injury status affects biomechanics during running, as well as hip strength and flexibility, may provide greater insight into the prevention of injury recurrence. Therefore, the purpose of this

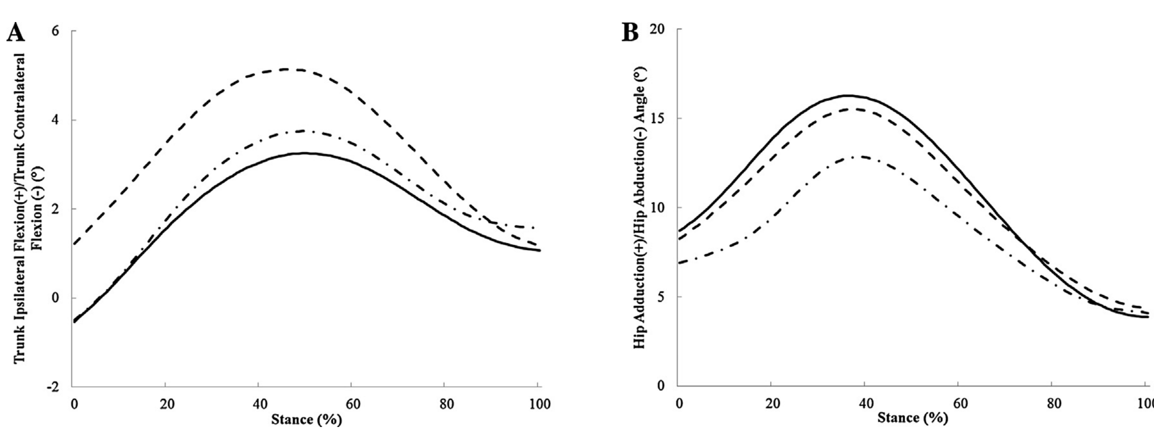

Fig. 1. (A) Trunk lateral flexion and (B) hip adduction during the stance phase of overground running in runners with current iliotibial band syndrome (ITBS) (dashed line), previous ITBS (dashdot line), and controls (solid line).

study was to determine if differences exist in biomechanics during running, hip abductor strength, and iliotibial band flexibility among women with current ITBS, previous ITBS, and controls.

Consistent with our hypothesis, runners with current ITBS exhibited greater trunk ipsilateral flexion than controls. Greater trunk ipsilateral flexion was expected to result in a lesser hip abductor moment during running. However, the hip abductor moment was similar among groups which is consistent with previous ITBS investigations [10,13]. Additionally, trunk ipsilateral flexion was similar between runners with previous ITBS and controls which is in agreement with a separate study [14]. Furthermore, we did not find a difference in contralateral pelvic drop among groups. No difference in contralateral pelvic drop between runners with previous ITBS and controls is consistent with the literature [14]. Therefore, it appears that the peak hip abductor moment and contralateral pelvic drop during running are not associated with ITBS.

The iliotibial band aids in maintaining pelvic alignment in the frontal plane [26]. Altered iliotibial band function would affect pelvic control, thereby increasing trunk ipsilateral flexion [26]. Increased trunk ipsilateral flexion may influence iliotibial band tightness due to two potential mechanisms. First, the iliotibial band may become tight as a consequence of reduced strain due to trunk position during the stance phase of running. Second, a tight iliotibial band may result in greater trunk ipsilateral flexion. Runners with previous ITBS may not exhibit iliotibial band tightness since flexibility is targeted in rehabilitation for ITBS, and they ran with a more upright trunk compared to runners with current ITBS. No difference in iliotibial band flexibility in runners with previous ITBS is in agreement with a previous ITBS study [27]. Additionally, all runners in the previous ITBS group reported they had participated in therapy that included hip stretching as directed by their health care provider. Therefore, it is likely that as a result of rehabilitation iliotibial band flexibility increased to a level that is similar to controls.

It has been postulated that runners with current knee pain may lean their trunk more towards the stance limb as a consequence of weak hip abductors [19]. Contrary to our hypothesis, runners with current ITBS exhibited similar isometric hip abductor strength compared to controls. However, runners with previous ITBS exhibited less isometric hip abductor strength than controls. The literature differs in implicating isometric hip abductor strength as a factor associated with ITBS [9,15]. Strengthening the hip abductors is a component of rehabilitating runners with current ITBS [28]. Therefore, targeting lower extremity musculature particularly the hip abductor via strength training may benefit both current and previously injured runners.

Contrary to our hypothesis, the peak hip adduction angle was less in runners with previous ITBS compared runners with current ITBS and controls. Furthermore, peak hip adduction was similar between runners with current ITBS and controls. The inclusion of both runners with current ITBS and previous ITBS allows for associations to be made on how biomechanics during running is influenced by ITBS injury status. Similar hip adduction between runners with current ITBS and controls may be related to greater trunk lean demonstrated by runners with current ITBS. By positioning the trunk more towards the stance limb, the current ITBS group may have exhibited a strategy allowing them to maintain a level pelvis. Consequently, this would reduce the hip adduction angle and may reduce pain associated with ITBS. In runners with previous ITBS, the smaller hip adduction demonstrated suggests a different frontal plane movement pattern may develop after ITBS symptoms subsided. A compensatory running strategy aimed at decreasing hip adduction along with a positioning the trunk upright may decrease iliotibial band strain and tightness. Furthermore, the pain associated with ITBS may have decreased by adopting a different running strategy. However, due to the cross-sectional design of this study, we do not know if biomechanics during running changed as a result of ITBS.

No significant differences were observed in peak knee internal rotation among runners with current ITBS, previous ITBS, and controls. This is contrary to previous studies that reported that women who later developed ITBS and women with previous ITBS exhibit greater knee internal rotation than controls [10,13]. However, the measurement error associated with quantifying knee rotation during running using a skin marker based optical motion capture system is high [29]. Therefore, caution should be taken when associating knee rotation angles with injury status in biomechanics during running. Collectively, it remains unclear if peak knee internal rotation angle is a robust biomechanical factor associated with ITBS.

Limitations of the current study are noted. The ranges of time that participants were currently experiencing ITBS symptoms and the time since ITBS symptoms subsided were large. However, this may increase the generalizability of the results in female runners with current ITBS and previous ITBS. Furthermore, by including two different ITBS groups, this allowed for conclusions to be made on how runners with current ITBS differ from those whose ITBS symptoms have resolved. Additionally, multiple ANOVAs were implemented which increases the likelihood of Type I error. A Bonferroni correction was not used because its purpose is to test the general null hypothesis which was not of interest here.

5. Conclusion

Collectively, these results suggest that greater trunk ipsilateral flexion may be a consequence of ITBS. This trunk motion strategy demonstrated by runners with current ITBS may have reduced the demands placed on the hip abductors. Therefore, the lower hip abductor strength demonstrated by runners with previous ITBS compared to controls may be a residual effect of excessive trunk ipsilateral flexion due to injury. ITBS interventions should target proper trunk motion during running, as well as strengthen lower extremity musculature even after ITBS symptoms subside. Lastly, runners with previous ITBS exhibited smaller peak hip adduction angles compared to runners with previous ITBS and controls. Less hip adduction and running with a more vertical trunk during running may be a compensatory strategy to decrease pain when injured.

Conflict of interest statement

None.

References

[1] U.S. Bureau of Labor Statisitics. Table no. 1249. Participation in selected sports activities: 2009. Washington, DC: U.S. Census Bureau; 2012. 768.

[2] Fehling PC, Alekel L, Clasey J, Rector A, Stillman RJ. A comparison of bone mineral densities among female athletes in impact loading and active loading sports. Bone 1995;17(3):205–10.

[3] Ingjer F. Effects of endurance training on muscle fibre ATP-ase activity, capillary supply and mitochondrial content in man. J Physiol 1979;294:419–32.

[4] Bovens AM, Janssen GM, Vermeer HG, Hoeberigs JH, Janssen MP, Verstappen FT. Occurrence of running injuries in adults following a supervised training program. Int J Sports Med 1989;10(Suppl. 3):S86–90.

[5] Lun V, Meeuwisse WH, Stergiou P, Stefanyshyn D. Relation between running injury and static lower limb alignment in recreational runners. Br J Sports Med 2004;38(5):576–80.

[6] Macera CA, Pate RR, Powell KE, Jackson KL, Kendrick JS, Craven TE. Predicting lower-extremity injuries among habitual runners. Arch Intern Med 1989;149(11):2565–8.

[7] Daoud AI, Geissler GJ, Wang F, Saretsky J, Daoud YA, Lieberman DE. Foot strike and injury rates in endurance runners: a retrospective study. Med Sci Sports Exerc 2012;44(7):1325–34.

[8] 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(2):95–101.
[9] 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(3):169–75.
[10] 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(9):951–6.
[11] Hamill J, Miller R, Noehren B, Davis I. A prospective study of iliotibial band strain in runners. Clin Biomech (Bristol Avon) 2008;23(8):1018–25.
[12] Fairclough J, Hayashi K, Toumi H, Lyons K, Bydder G, Phillips N, 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(3):309–16.
[13] Ferber R, Noehren B, Hamill J, Davis IS. Competitive female runners with a history of iliotibial band syndrome demonstrate atypical hip and knee kinematics. J Orthop Sports Phys Ther 2010;40(2):52–8.
[14] Foch E, Milner CE. The influence of iliotibial band syndrome history on running biomechanics examined via principal components analysis. J Biomech 2014;47(1):81–6.
[15] Grau S, Krauss I, Maiwald C, Best R, Horstmann T. Hip abductor weakness is not the cause for iliotibial band syndrome. Int J Sports Med 2008;29(7):579–83.
[16] Noehren B, Schmitz A, Hempel R, Westlake C, Black W. Assessment of strength, flexibility, and running mechanics in men with iliotibial band syndrome. J Orthop Sports Phys Ther 2014;44(3):217–22.
[17] Ireland ML, Willson JD, Ballantyne BT, Davis IM. Hip strength in females with and without patellofemoral pain. J Orthop Sports Phys Ther 2003;33(11):671–6.
[18] Piva SR, Goodnite EA, Childs JD. Strength around the hip and flexibility of soft tissues in individuals with and without patellofemoral pain syndrome. J Orthop Sports Phys Ther 2005;35(12):793–801.
[19] Noehren B, Pohl MB, Sanchez Z, Cunningham T, Lattermann C. Proximal and distal kinematics in female runners with patellofemoral pain. Clin Biomech (Bristol Avon) 2012;27(4):366–71.
[20] Taunton JE, Ryan MB, Clement DB, McKenzie DC, Lloyd-Smith DR, Zumbo BD. A prospective study of running injuries: the Vancouver Sun Run in Training clinics. Br J Sports Med 2003;37(3):239–44.
[21] Faul F, Erdfelder E, Lang AG, Buchner A. G*Power 3: a flexible statistical power analysis program for the social, behavioral, and biomedical sciences. Behav Res Methods 2007;39(2):175–91.
[22] Noehren B, Scholz J, Davis I. The effect of real-time gait retraining on hip kinematics, pain and function in subjects with patellofemoral pain syndrome. Br J Sports Med 2011;45(9):691–6.
[23] Thomas S, Reading J, Shepard RJ. Revision of the physical activity readiness questionnaire (PAR-Q). Can J Sport Sci 1992;17(4):338–49.
[24] Bisseling RW, Hof AL. Handling of impact forces in inverse dynamics. J Biomech 2006;39(13):2438–44.
[25] Wu G, Cavanagh PR. ISB recommendations for standardization in the reporting of kinematic data. J Biomech 1995;28(10):1257–61.
[26] Grimaldi A. Assessing lateral stability of the hip and pelvis. Man Ther 2011;16(1):26–32.
[27] Miller RH, Lowry JL, Meardon SA, Gillette JC. Lower extremity mechanics of iliotibial band syndrome during an exhaustive run. Gait Posture 2007;26(3):407–13.
[28] Fredericson M, Weir A. Practical management of iliotibial band friction syndrome in runners. Clin J Sport Med 2006;16(3):261–8.
[29] Reinschmidt C, van den Bogert AJ, Nigg BM, Lundberg A, Murphy N. Effect of skin movement on the analysis of skeletal knee joint motion during running. J Biomech 1997;30(7):729–32.