Lower Limb Biomechanical Factors Related to Running Injuries: A Review and Practical Recommendations

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ABSTRACT

THE OBJECTIVE OF THIS REVIEW IS TO ANALYZE SOME OF THE BIOMECHANICAL FACTORS INVOLVED IN THE MOST COMMON RUNNING INJURIES: ANTERIOR KNEE PAIN, ILIOTIBIAL BAND SYNDROME, ACHILLES TENDINOPATHY, AND MEDIAL TIBIAL STRESS SYNDROME/TIBIAL STRESS FRACTURE. EIGHTEEN STUDIES MET ALL INCLUSION CRITERIA. RESULTS SHOWED THAT THERE IS LITTLE CONSISTENT EVIDENCE IN THE LITERATURE TO CONNECT ANY BIOMECHANICAL ANOMALY TO ANY GIVEN RUNNING INJURY, EXCEPT FOR FEMALE RUNNERS WITH PATELLOFEMORAL PAIN WHO HAVE AN INCREASED PEAK HIP ADDUCTION ANGLE AT STANCE PHASE. THIS REVIEW SUGGESTS THAT ASSESSING AND TREATING HIP MECHANICS COULD HELP TO PREVENT KNEE INJURIES IN FEMALE RUNNERS.

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INTRODUCTION

Throughout the past decades, running has become a popular form of exercise because it is affordable, is accessible, and has important health benefits, including a reduction of risk factors in cardiovascular disease and obesity (30,51). However, despite these benefits, running is one of the most widespread activities during which overuse injuries of the lower extremity occur, both in recreational and competitive athletes (14). According to Buist et al. (8) and Johnston et al. (25) a combination of extrinsic and intrinsic factors may lead to overuse running injuries. Extrinsic factors include running surface, running shoes, and running distance per week. Intrinsic factors include age, gender, muscle strength, flexibility and malalignment of the leg and are related to individual characteristics of runners.

Taunton et al. (51) carried out an investigation with a total of 2002 patients who presented running-related injuries. They listed the frequency and gender distribution of the most common injuries, and this information has been used in this review. Table 1 shows the 10 most common overuse injuries in running according to Taunton et al. (51). We have grouped patellofemoral pain (PFP) and patellar tendinopathy (PT) as anterior knee pain because symptoms occur at the front and center of the knee. There are 4 different types of injury under the scope of this systematic review grouped in knee injuries and lower leg injuries: anterior knee pain (PFP/PT), iliotibial band syndrome (ITBS), Achilles tendinopathy (AT), and tibial stress syndrome/tibial stress fracture (TSS/TSF). We have not considered the other 6 because of their low incidence rate, great gender differences, or the lack of kinematic measures in the studies carried out to date.

KEY WORDS:
running biomechanics; hip adduction; rearfoot eversion; injury prevention; hip abductor muscle strengthening program; running retraining

Table 1
Frequency and gender distribution of the 10 most common injuries

Pathologies	Total n	Men n1	Men %	Women n2	Women %
Anterior knee pain (PFP and patellar tendinopathy)	427	179	42	248	58
Iliotibial band syndrome	168	63	38	105	42
Plantar fasciitis	158	85	54	73	56
Tibial stress syndrome/stress fracture	166	70	42	96	58
Meniscal injuries	100	69	69	31	31
Achilles tendinopathy	96	56	58	40	42
Gluteus medius injuries	70	17	24	53	76
Spinal injuries	47	24	51	23	49
Hamstring injuries	46	25	54	21	46
Metatarsalgia	24	17	50	17	50

Modified from Taunton et al. (51).

PFP= patellofemoral pain.

KNEE INJURIES: ANTERIOR KNEE PAIN AND ILIOTIBIAL BAND SYNDROME

Among physically active individuals, the knee has been reported to be the most common site of overuse injuries (14,43,51). According to Reiman et al. (45), research conducted in the past decades suggests that proximal factors, such as hip muscle weakness or deficits in trunk control, may contribute to overuse knee injuries. Ferber et al. (14) concluded that a large number of studies suggest that weakness of hip-stabilizing muscles leads to atypical lower extremity mechanics, increasing loading forces and risk of injuries. Aderem and Louw (1) affirm that despite the limited numbers of studies, the small effect sizes found and the lack of methodological rigor of the studies included in their systematic review, female shod runners with ITBS presented increased peak knee internal rotation angle during the stance phase of running. Neal et al. (36) show moderate evidence that there is a relationship between PFP and increased peak hip adduction and between PFP and increased peak hip internal rotation angle.

LOWER LEG INJURIES: TIBIAL STRESS SYNDROME/STRESS FRACTURE AND ACHILLES TENDINOPATHY

Regarding the injuries below the knee joint, Myerson (35) suggests that dysfunction of the posterior tibial tendon may result in an exaggerated eversion of the calcaneus, an internal rotation of the tibia, and a pathologic flatfoot deformity, and all of these factors could increase lower leg injury risk. Ness et al. (37) compared the gait of patients with posterior tibial tendon dysfunction with that of a group of healthy individuals and found no differences in tibial internal rotation, but the loss of the longitudinal arch lead to an increased eversion of the rearfoot. However, Ferber et al. (14) found no definitive link between atypical foot mechanics and running injuries in their systematic review.

In recent years, there has been an exponential increase in research studying running-related injuries from a biomechanical perspective. Therefore, the purpose of this review is to determine the biomechanical factors that may lead to one of the following overuse running pathologies: PFP/PT, ITBS, AT and TSS/TSF, including the most recent articles that are not present in the past systematic reviews. Only the most analyzed kinematic variables that were common to those 4 pathologies were considered in this review.

SEARCH STRATEGY

After a broad strategy search approach, we considered a total of 18 articles appropriate for this review. The following medical electronic databases were searched from January 1, 2005, to January 31, 2018: PubMed, Science Direct, Web of Science and Scopus, using the following search terms: "running" and "injury," combining them with Boolean operators with other terms such as "kinematics," "biomechanics," "analysis," or "mechanics."

Included articles met the following criteria: studies involving male or female runners (recreational or competitive) with a medical diagnosis of injury related to running; that assessed one of the following injuries seen in running: PFP/PT, ITBS, AT and TSS/TSF; that compared injured runners with healthy control runners directly via significant differences; with a prospective or case-control study design; in English or Spanish; with 3-dimensional (3D) kinematic outcome measures captured during treadmill or overground running; with a minimum sample size of 8 runners, that measured at least one of these kinematic variables: peak hip adduction, hip internal rotation, knee internal rotation, and rearfoot eversion angles at stance phase.

Once they were selected, we classified them in articles that measured kinematic variables at stance in runners with PFP/PT (11,13,18,39,40,46), ITBS (7,15–17,19,38), AT (12,47,53), and TSS/TSF (31,33). One of these articles names the running injury as medial shin pain (31). One article measured both, AT and TSS (5). We scored all articles as moderate quality based on evaluation with the Critical Appraisal Form for Quantitative Studies (27) (Table 2).

RESULTS

CHARACTERISTICS OF INCLUDED STUDIES

A summary of study characteristics for included articles can be seen in Table 3.

MAIN RESULTS

Kinematic variables in runners with knee injuries.

Anterior knee pain. Six studies analyzed runners with anterior knee pain, 5 of them investigated runners with PFP (11,13,39,40,46), and 1 of them runners with PT (18). Five studies measured peak hip adduction angle (11,13,18,39,40). Two of them found a significantly greater peak hip adduction in female runners with PFP when compared with healthy control runners (39,40). In the study of Grau et al. (18), female runners with PT showed a tendency toward a greater peak hip adduction. On the contrary, Dierks et al. (11) obtained a significantly smaller peak hip adduction angle in the PFP group when compared with control group. Only Esculier et al. (13) found no significant differences in peak hip adduction angle between PFP and healthy groups.

Four studies investigated hip internal rotation (11,13,39,40). Only Noehren et al. (39) found significantly greater peak hip internal rotation in female runners with PFP, whereas no significant differences between groups were found in the others. We did not find significant differences between injured and healthy groups in articles that analyzed rearfoot eversion (11,18,39,40,46) and knee internal rotation (11,46).

Iliotibial band syndrome. We selected 6 articles (7,15–17,19,38). All of the articles analyzed peak hip adduction angles (7,15–17,19,38), but only 5 studies found significant differences between injured and healthy runners (7,15,17,19,38). Two studies found a significantly greater peak hip adduction angle during the stance phase in female runners, one of them in runners who had previously sustained ITBS (15) and the other in females who developed this injury later in a prospective design (38). On the other hand, 3 studies observed a lower peak hip adduction angle, 2 of them in female runners with ITBS (7,17) and the other in male and female runners with ITBS (19). Brown et al. (7) found this result only when runners are fatigued, and Foch et al. (17) found this result only in female runners with a history of ITBS but not in runners with current injury.

Only one article analyzed peak hip internal rotation angle with no significant differences between the groups (7). Three studies measured peak knee internal rotation angle (15,17,38), 2 of them found a significantly greater peak angle in female runners with ITBS (15,38), whereas no significant differences were found in the other (17). Concerning the influence of ankle and foot in subjects with ITBS, we did not find significant differences between healthy and injured subjects in peak rearfoot eversion angle in all 3 articles that measured it (15,19,38).

Kinematic variables in runners with lower leg injuries.

Achilles tendinopathy. Three of the 4 included articles measured rearfoot eversion angle, and none of them found significant differences between injured and healthy groups (5,12,47). Only 1 study measured knee internal rotation (53), and it showed that injured subjects had significantly less peak internal rotation angle at the knee than healthy control subjects. Peak hip adduction and peak hip internal rotation angles were not measured in any study.

Tibial stress syndrome/stress fracture. We included 3 studies (5,31,33). Two studies measured rearfoot eversion angles (5,33). Milner et al. (33) demonstrated that the injured group exhibited significantly greater peak rearfoot eversion angle compared with healthy control group, whereas no significant differences between the groups were found by Becker et al. (5).

Two studies analyzed peak hip internal rotation angle (31,33) and only 1 of them found a significantly greater peak angle in injured runners (31), whereas no significant differences were found in the other (33). Only one study analyzed peak hip adduction angle and showed a significantly greater peak hip adduction angle in injured runners (33). We did not find significant differences between groups in the only article that analyzed the knee internal rotation angle (33).

Table 4 shows the kinematic variables measured in all the studies included in this review.

DISCUSSION

KINEMATIC VARIABLES IN RUNNERS WITH ANTERIOR KNEE PAIN

Our findings suggest that there is moderate evidence of an association between PFP and increased peak hip adduction. The different results found in 2 of the 6 studies analyzed (11,13) may be to the result of gender differences because those 2 studies also included men (11,13). These findings support the results found by Neal et al. (36), who conclude that female runners with PFP have significantly increased peak hip adduction in comparison to male runners with PFP, and the results of Esculier et al. (13) who affirmed that females with PFP accounted for much of the kinematic differences for hip adduction angles.

There is no solid evidence of an association between PFP and an increase in hip internal rotation. The discrepancies found may be attributable to a variety of methodological factors such as the time point at which the values were selected in the stance phase, the kinematic models used, or even the inclusion criteria of the participants (39). Therefore, these results do not really support those found by Neal et al. (36) who affirmed that there is moderate evidence of an association between PFP and increased peak hip internal rotation angle.

Table 2
Methodological quality appraisal

	Items	Noehren et al. (39)	Noehren et al. (40)	Dierks et al. (11)	Esculier et al. (13)	Grau et al. (18)	Rodrigues et al. (46)	Brown et al. (7)	Ferber et al. (15)	Foch and Milner (16)
1.	The purpose of the study was clearly stated	+	+	+	+	+	+	+	+	+
2.	The study design was appropriate	+	+	+	+	+	+	+	+	+
3.	The study detected sample biases	−	−	−	−	−	−	−	−	−
4.	Measurement biases were detected in the study	−	−	−	−	−	−	−	−	−
5.	The sample size was stated	+	+	+	+	+	+	+	+	+
6.	The sample was described in detail	+	+	+	+	−	+	+	+	+
7.	The sample size was justified	−	+	+	−	−	+	−	+	+
8.	The outcomes were clearly stated and relevant to the study	+	+	−	−	−	−	+	+	+
9.	The method of measurement was described sufficiently	+	+	+	+	+	+	+	+	+
10.	Blinding of outcome assessor	−	−	−	−	−	−	−	−	−
11.	The measures used were valid and reliable	−	−	−	−	−	−	−	−	−
12.	The results were reported in terms of statistical significance	+	+	+	+	+	+	+	+	+
13.	The analysis methods used were appropriate	+	+	+	+	+	+	+	+	+

	Table 2 (continued)									
14.	Clinical importance was reported	+	+	+	+	+	+	+	+	−
15.	Missing data were reported where appropriate	−	+	−	−	+	−	−	−	−
16.	Conclusions were relevant and appropriate given the methods and results of the study	+	−	+	+	−	+	+	+	+
	Total CAT score	10	11	10	9	8	10	10	11	10
	Total CAT %	62.50	68.75	62.50	56.25	50	62.50	62.50	68.75	62.50
	Items	**Foch et al. (17)**	**Grau et al. (19)**	**Noehren et al. (38)**	**Donoghue et al. (12)**	**Ryan et al. (47)**	**Williams et al. (53)**	**Loudon and Reiman (31)**	**Milner et al. (33)**	**Becker et al. (5)**
1.	The purpose of the study was clearly stated	+	+	+	+	+	+	+	+	+
2.	The study design was appropriate	+	+	+	+	+	+	+	+	+
3.	The study detected sample biases	−	−	−	−	−	−	−	−	−
4.	Measurement biases were detected in the study	−	−	−	−	−	−	−	−	−
5.	The sample size was stated	+	+	+	+	+	+	+	+	+
6.	The sample was described in detail	+	+	+	−	+	+	+	+	+
7.	The sample size was justified	+	−	+	−	−	−	−	+	+
8.	The outcomes were clearly stated and relevant to the study	+	+	+	−	+	+	+	+	+

(continued)

Table 2 (continued)

9.	The method of measurement was described sufficiently	−	+	+	+	+	+	+	+	+
10.	Blinding of outcome assessor	−	−	−	−	−	−	−	−	−
11.	The measures used were valid and reliable	−	−	−	−	−	−	−	−	−
12.	The results were reported in terms of statistical significance	+	+	+	+	+	+	+	+	+
13.	The analysis methods used were appropriate	+	+	+	+	+	+	+	+	+
14.	Clinical importance was reported	+	+	+	+	+	+	+	+	+
15.	Missing data were reported where appropriate	−	+	+	−	−	−	+	−	−
16.	Conclusions were relevant and appropriate given the methods and results of the study	+	+	−	+	+	+	+	+	+
	Total CAT score	10	11	11	8	10	10	11	11	11
	Total CAT %	62.50	68.75	68.75	50	62.50	62.50	68.75	68.75	68.75

CAT = critical appraisal tool.

Table 3
Study characteristics

Study	Type of Injury (and status)	Sample size (N)		Sex Gender (M/F)		Age (years) mean ± SD		Weekly distance (km), mean ± SD		Footwear condition
		IG	CO	IG	CO			IG	CO	
Noehren et al. (39)	PFP (c)	16	16	0/16	0/16	27 ± 6	25 ± 4	23 ± 10	35 ± 16	Neutral shoe
Noehren et al. (40)	PFP (pro)	15	15	0/15	0/15	27 ± 10	27 ± 10	165 ± 53[a]	165 ± 43[a]	Neutral shoe
Dierks et al. (11)	PFP (c)	20	20	5/15	5/15	24.1 ± 7.4	22.7 ± 5.6	27.3 ± 11.1	24.6 ± 10.3	Neutral shoe
Esculier et al. (13)	PFP (c)	21	20	5/16	5/15	34.1 ± 6.0	33.2 ± 6.0	20.4 ± 4.4	24.0 ± 10.9	Own shoe
Grau et al. (18)	PT (c)	12	12	0/12	0/12	40[b]	39[b]	DNR	DNR	Barefoot
Rodrigues et al. (46)	PFP (c)	17	19	4/13	10/9	29.8 ± 7	34 ± 10	≥ 12.8[b]	≥ 12.8[b]	Neutral shoe
Brown et al. (7)	ITBS (c)	12	20	0/12	0/20	32.4 ± 7.9	28.9 ± 6.1	≥ 24[b]	≥ 24[b]	Neutral shoe
Ferber et al. (15)	ITBS (p)	35	35	0/35	0/35	35.4 ± 10.3	31.23 ± 11	123.8 ± 62.6[a]	119.2 ± 52[a]	Neutral shoe
Foch and Milner (16)	ITBS (p)	17	17	0/17	0/17	26.6 ± 6.6	25.4 ± 6.2	44.9 ± 26.1	44.7 ± 18.8	Neutral shoe
Foch et al. (17)	ITBS (c)	9	9	0/9	0/9	26.2 ± 7.9	25.3 ± 7.0	34.8 ± 23.5	45.2 ± 22.5	Neutral shoe
Foch et al. (17)	ITBS (p)	9	9	0/9	0/9	24.7 ± 5.2	25.3 ± 7.0	35.2 ± 18.7	45.2 ± 22.5	Neutral shoe
Grau et al. (19)	ITBS (c)	18	18	13/5	13/5	36 ± 7	37 ± 9	≥ 20[b]	≥ 20[b]	Barefoot
Noehren et al. (38)	ITBS (pro)	18	18	0/18	0/18	26.8[b]	28.5[b]	96.2[ab]	99.3[ab]	Neutral shoe
Donoghue et al. (12)	AT (p)	11	11	10/1	10/1	39.6 ± 7.7	45.2 ± 8.1	DNR	DNR	Barefoot/own shoe
Ryan et al. (47)	AT (c)	27	21	27/0	21/0	40 ± 7	40 ± 9	≥30[b]	≥30[b]	Barefoot
Williams et al. (53)	AT (p)	8	8	6/2	5/3	36 ± 8.2	31.8 ± 9.3	41.3 ± 20.8	35.3 ± 23.1	Barefoot
Becker et al. (5)	AT (c)	13	13	9/4	9/4	37.6 ± 15.9	32.6 ± 12.4	80 ± 24	84.1 ± 23.6	Own shoe
Loudon and Reiman (31)	TSS/TSF (p)	14	14	6/8	6/8	29.2 ± 5.9	26.5 ± 5.39	33.9 ± 26.4	27.82 ± 22.4	Own shoe
Milner et al. (33)	TSS/TSF (p)	29	29	0/29	0/29	28 ± 10	26 ± 9	43 ± 12	46 ± 21	Neutral shoe
Becker et al. (5)	TSS/TSF (c)	8	8	7/1	7/1	35.3 ± 11.8	36.4 ± 9.7	44.2 ± 9.6	46.3 ± 11.9	Own shoe

[a]Calculated in kilometers per month.

[b]Some authors did not provide the mean or the SD.

AT = achilles tendinopathy group; c = current injury; CO = control healthy group; DNR = did not report; F = female; IG = injured group; ITBS = iliotibial band syndrome group; M = male; n = number of participants; p = previous injury; PFP = patellofemoral pain group; pro, prospective study design; PT = patellar tendinopathy group; TSS/TSF = tibial stress syndrome or tibial stress fracture group.

Table 4
Summary of biomechanical findings

Study	Type of injury (and status)	Significant kinematic differences: Mean ± SD; *P*; size effect (δ)	Nonsignificant kinematic differences	Kinematic variables not measured
Noehren et al. (39)	PFP (c)	>HADD: 20.0° ± 3.5°; *P* = 0.046; δ = 0.71 >HIR: 9.8° ± 4.2°; *P* = 0.002; δ = 1.22	REV	KIR
Noehren et al. (40)	PFP (pro)	>HADD: 12.1° ± 2.8°; *P* = 0.007; δ = 1.07	HIR REV	KIR
Dierks et al. (11)	PFP (c)	<HADD: 8.8° ± 5.7°; *P* < 0.05; δ = 0.63	HIR REV KIR	—
Esculier et al. (13)	PFP (c)	—	HADD HIR	REV KIR
Grau et al. (18)	PT (c)	Trend toward >HADD: 15.0° ± 3.0°; *P* < 0.1; δ = 0.85	REV	HIR KIR
Rodrigues et al. (46)	PFP (c)	—	KIR REV	HIR HADD
Brown et al. (7)	ITBS (c)	<HADD (as a result of fatigue): 13.9° ± 4.1°; *P* = 0.03; δ = 0.84	HIR	REV KIR
Ferber et al. (15)	ITBS (p)	>HADD: 10.39° ± 4.36°; *P* = 0.05; δ = 0.48 >KIR: 1.75° ± 5.94°; *P* = 0.03; δ = 0.53	REV	HIR
Foch and Milner (16)	ITBS (p)	—	HADD	HIR KIR REV
Foch et al. (17)	ITBS (c, p)	<HADD in runners with previous injury: 13.4° ± 3.2°; *P* = 0.02; δ = 1.22	KIR	REV HIR
Grau et al. (19)	ITBS (c)	<HADD: 9.0° ± 3.0°; *P* < 0.05; δ = 1.13	REV	HIR KIR
Noehren et al. (38)	ITBS (pro)	>HADD: 14.1° ± 2.5°; *P* = 0.01; δ = 0.87 >KIR: 3.9° ± 3.7°; *P* = 0.01; δ = 0.93 Trend toward <REV: 9.7° ± 3.3°; *P* = 0.07; δ = 0.65	—	HIR
Donoghue et al. (12)	AT (p)	—	REV	HIR KIR HADD
Ryan et al. (47)	AT (c)	—	REV	HIR KIR HADD

Table 4 (continued)

Williams et al. (53)	AT (p)	<KIR: 3.1° ± 3.8°; *P* = 0.05; δ = 0.97	—	HIR HADD REV
Becker et al. (5)	AT (c)	—	REV	HIR KIR HADD
Loudon and Reiman (31)	TSS/TSF (p)	>HIR: 11.48° ± 5.2°; *P* = 0.004; δ = 1.18	—	REV HADD KIR
Milner et al. (33)	TSS/TSF (p)	>REV: 11.7 ± 4.2°; *P* = 0.015; δ = 0.67 >HADD: 11.6° ± 5.0°; *P* = 0.004; δ = 0.80	HIR KIR	—
Becker et al. (5)	TSS/TSF (c)	—	REV	HIR KIR HADD

AT = achilles tendinopathy group; c = current injury; CO = control healthy group; HADD = peak hip adduction angle at stance; HIR = peak hip internal rotation angle at stance; IG = injured group; ITBS = iliotibial band syndrome group; KIR = peak knee internal rotation angle at stance; p = previous injury; PFP = patellofemoral pain group; pro = prospective study design; PT = patellar tendinopathy group; REV = peak rearfoot eversion angle at stance; TSS/TSF = tibial stress syndrome or tibial stress fracture group.

Figure 1. Example of kinematics abnormalities identified with a video-based running analysis. Runner with excessive hip adduction at stance (A and B). Comparison of heel eversion at stance (C and D). Greater rearfoot eversion on the right foot at stance (C). Comparison of maximum rotation of plantar surface of the shoe at swing phase (E and F). Greater medial rotation of plantar surface of the left shoe at swing that could involve a greater lower limb internal rotation during running (E).

None of the studies found an association between PFP and rearfoot eversion (11,18,39,40,46), confirming the results found by Neal et al. (36). An association between PFP and knee internal rotation was not found in any study (11,46).

KINEMATIC VARIABLES IN RUNNERS WITH ILIOTIBIAL BAND SYNDROME

Regarding peak hip adduction angle, we found major discrepancies in runners with ITBS, which may be explained by ITBS injury status. Female healthy runners who will develop ITBS in the future showed a greater peak hip adduction angle compared with healthy subjects. Female runners with current injury showed no significant differences, whereas female runners with a history of injury showed less peak hip adduction. These ideas are in accordance with those of Foch et al. (17). They explain that the current ITBS group may have exhibited a strategy to maintain the level of the pelvis that would reduce the hip adduction angle and the pain associated with ITBS. After symptoms subsided, runners with previous ITBS may have found a compensatory running strategy at decreasing hip adduction along with other biomechanical changes that may decrease iliotibial band strain. The results found by Brown et al. (7) seem to support our hypothesis because they conclude that female runners with ITBS modify their running gait to decrease hip adduction, potentially as a result of pain.

However, future research is needed because 2 studies found different results (15,19). There is moderate evidence of an association between female runners with ITBS and increased peak knee internal rotation angle. Concerning the results found in peak rearfoot eversion in runners with ITBS, we can conclude that this biomechanical factor is not associated with the development of this type of injury.

KINEMATIC VARIABLES IN RUNNERS WITH ACHILLES TENDINOPATHY

Regarding peak rearfoot eversion, none of the studies found significant differences between injured and healthy groups (5,12,47), which contradicts the accepted idea that a large degree of rearfoot eversion at midstance may strain medial fibers of the Achilles tendon, increasing the risk of injury (47). However, Munteanu and Barton (34) showed an increased eversion range of motion of the rearfoot in runners with AT, which indicates that it is the biomechanical factor that may be related to injury risk.

KINEMATIC VARIABLES IN RUNNERS WITH TIBIAL STRESS SYNDROME/STRESS FRACTURE

Regarding peak rearfoot eversion, one study (33) found greater peak rearfoot eversion angle in the injured group and the other one (5) found no significant differences between the groups. However, the latter (5) showed that injured individuals had a more everted heel at heel off and a longer duration of eversion, suggesting that the important biomechanical factor related to injury risk may not only be the peak rearfoot

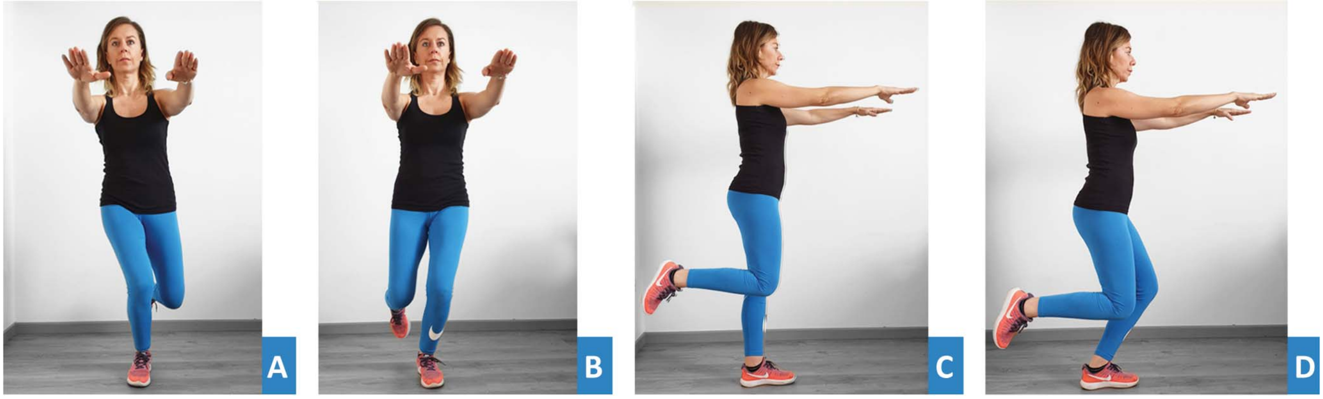

Figure 2. Single-leg squat. Right (A) and Left leg (B) asymmetry assessment during SLS. Start (C) and finish (D) position.

eversion angle but also the eversion range of motion, the duration of eversion, or even the eversion later in stance as it is suggested by Becker et al. (5).

The discrepancies found in peak hip internal rotation angle and the low number of studies analyzing peak hip adduction and knee internal rotation angles indicate that future research is needed.

LIMITATIONS

We identified methodological limitations during the quality assessment process. This resulted in all articles being ranked as moderate quality. All studies used 3D camera motion capture systems with retroreflective markers for tracking 3D movement that are extremely reliable, but it requires some human interaction (e.g., marker placement directly on the skin or on the shoe), which introduces opportunities for measurement errors. There was a wide variety of weekly running distance represented that introduced heterogeneity. We also believe that the different footwear conditions may introduce important bias by affecting running gait pattern of participants.

There were a limited number of studies that met all the inclusion criteria and not all of them assessed the 4 kinematic variables considered in this review, which would have been helpful to draw appropriate conclusions. Besides, most of the studies were conducted only with women. It would have also been desirable to have studies with a more balanced distribution of male and female subjects.

Only 2 studies (38,40) carried out a prospective research design. Because most of the studies are conducted with subjects who were already injured at the time of measurement, further prospective research is needed to overcome these limitations.

To conclude, there is little consistent evidence in the literature to connect any biomechanical anomaly to any given running injury, except for female runners with PFP who have an increased peak hip adduction angle at stance phase. It does seem that there is evidence that assessing and addressing hip biomechanics might help with female runners who have PFP.

PRACTICAL APPLICATIONS

This article reviews the influence of 4 biomechanical factors in the development of 4 of the more common running-related injuries. According to this review, practitioners should assess

Figure 3. Ankle dorsiflexion assessment and treatment. Final participant position for the weight-bearing lunge using the distance-to-wall technique, left (A) and right (B) ankle dorsiflexion range of motion. Ankle self-stretching using a strap, initial (C), and final (D) positions. Progression with an incline board (E).

hip mechanics to prevent running injuries at the knee (PFP/PT and ITBS), especially in women.

SCREENING TESTS FOR BIOMECHANICAL IMPAIRMENTS IN RUNNERS

Many of the kinematic abnormalities identified in runners with injuries can be measured using a systematic 2-dimensional video-based running analysis using readily available and fairly inexpensive tools (49). To conduct this 2-dimensional video-based running analysis optimally, Souza's (49) method and interpretation is recommended (Figure 1).

There are also many practical tests to easily evaluate kinematic abnormalities. According to this article, practitioners should assess hip mechanics to prevent running injuries at the knee, especially in women. The single-leg squat test (SLS) (Figure 2) is a useful clinical test to provide a simple and convenient assessment of neuromuscular control for the lumbo-pelvic region (2,42,50). It is assumed SLS performance reflects that which is likely to occur during more complex tasks such as gait and running (3). Poor SLSs are characterized by excessive peak hip joint adduction relative to good SLSs (21). To conduct this research optimally, Livengood's (29) method and interpretation is recommended.

The assessment of ankle dorsiflexion range of motion (DF ROM) in the clinical setting is important because it has been linked to Achilles and patellar tendon injuries (32,44,52). When an athlete lacks sufficient ankle DF ROM, excessive pronation of the foot complex may be necessary to compensate and consequently increase the internal rotation of the tibia, leading

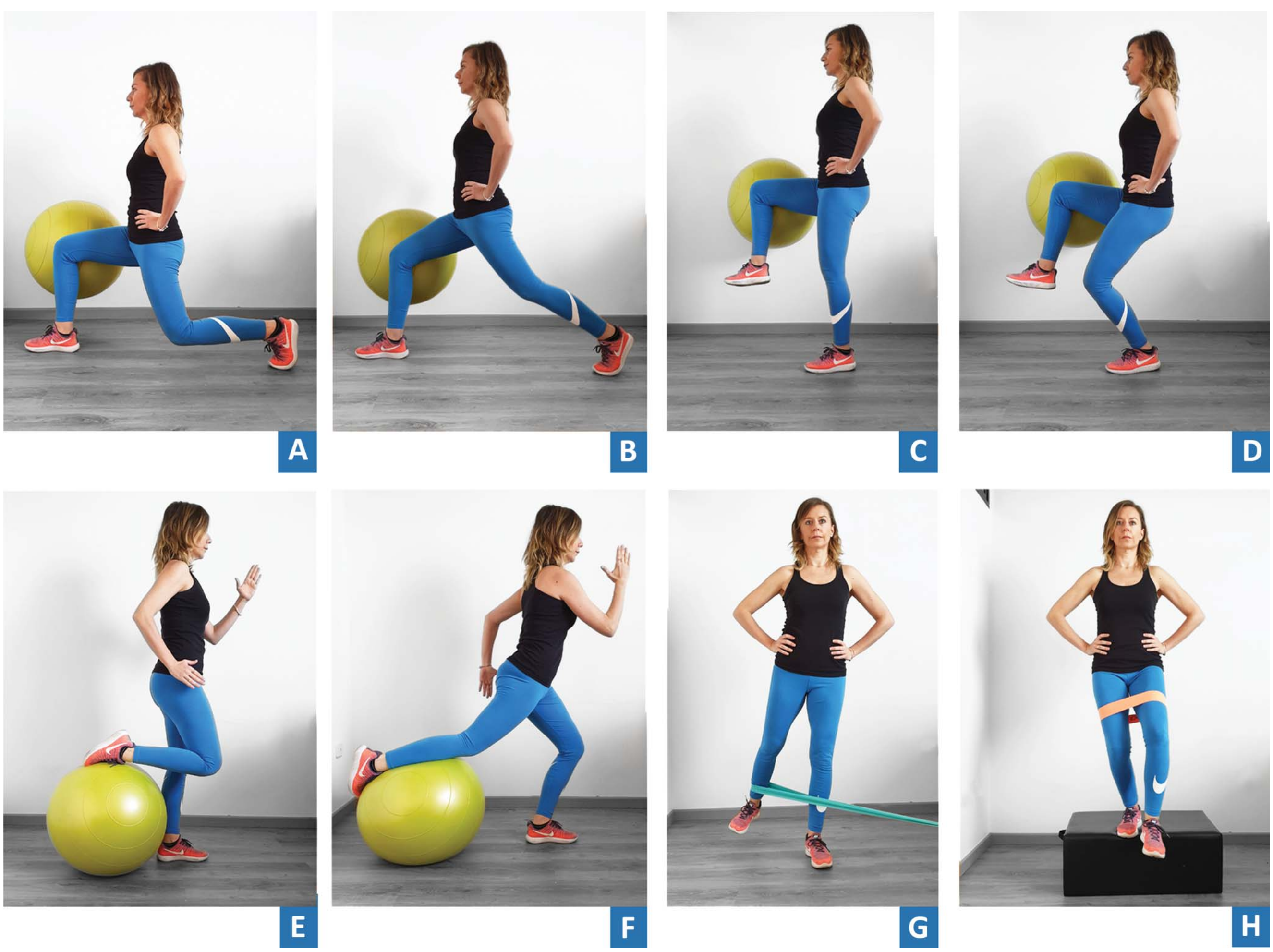

Figure 4. Sequence of hip muscles stabilizers strengthening and mobility program. Initial (A) and final (B) participant position for a lunge exercise with the ball between the wall and the lateral part of the knee trying to activate hip lateral stabilizers with a correct lower limb alignment. Initial (C) and final (D) participant position for a single-leg squat keeping the ball with the non–weight bearing leg. Initial (E) and final (F) participant position for a hip extension exercise adapted to runners. Hip abduction/external rotation exercise keeping the knee straight and the pelvis stable (G). Step-down exercise using a resistance band above the knees trying to keep lower limbs aligned (H).

to possible injuries (22). A meta-analysis showed that reduced DF ROM is associated with participants presenting with dynamic knee valgus compared with control subjects (28). Bell-Jenje et al. (6) associated a reduced ankle DF ROM with increased hip adduction but not with hip internal rotation during the step-down test.

We recommend the weight-bearing lunge (Figures 3A and 3B) using a standard goniometer, digital inclinometer, or a tape measure using the distance-to-wall technique because they have good reliability to measure ankle DF ROM (26). For improving ankle mobility, Jeon et al. (24) showed that a self-stretching technique using a strap positioned to improve the posterior glide of the talus while concurrently stretching the plantar flexor musculature (Figure 3C–3E) significantly increased ankle DF ROM during the weight-bearing lunge test.

REHABILITATION PROGRAM FOR BIOMECHANICAL IMPAIRMENTS IN RUNNERS

Running retraining of visual (real-time 3D feedback or mirror) and verbal faded feedback have significant results in reducing peak hip adduction (4,41,54). An important aspect to be considered is the step rate manipulation during running retraining. Heiderscheit et al. (20) found that a 5–10% increase in step rate can significantly reduce peak hip adduction and the loading to the hip and knee joints during running. They also indicated that running with a step rate greater than preferred reduces the biomechanical demands incurred by the hip in the frontal and transverse planes of motion and therefore may be useful in the clinical management of running injuries involving the hip.

A hip abductor muscle strengthening protocol could control the dynamic knee valgus because these muscles have been theorized to eccentrically control hip adduction during the stance phase of running (9,10,23). A strengthening program for hip abductors and external rotators is effective in reducing rearfoot eversion ROM and hip internal rotation ROM (48).

We recommend a rehabilitation program targeting hip muscle stabilizers strengthening and hip mobility to improve running biomechanics of the lower limb.

Figure 4 summarizes the sequence of hip muscle stabilizers strengthening and mobility program for runners.

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