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Kinematic risk factors for lower limb tendinopathy in distance runners: A systematic review and meta-analysis

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ABSTRACT

Introduction: Abnormal kinematics have been implicated as one of the major risk factors for lower limb tendinopathy (LLT).
Objective: To systematically review evidence for kinematic risk factors for LLT in runners.
Methods: Individual electronic searches in PubMed, EMBASE and Web of Science were conducted. Two reviewers screened studies to identify observational studies reporting kinematic risk factors in runners with LLT compared to healthy controls. The Down and Black appraisal scale was applied to assess quality. A meta-analysis was performed provided that at least two studies with similar methodology reported the same factor.
Results: Twenty-eight studies were included: Achilles tendinopathy (AT) (9), iliotibial band syndrome (ITBS) (17), plantar fasciopathy (PF) (2), patellar tendinopathy (PT) (1), posterior tibial tendon dysfunction (PTTD) (1). Eighteen studies were rated high-quality and ten medium-quality. The meta-analyses revealed strong evidence of higher peak knee internal rotation, moderate evidence of lower peak rearfoot eversion and knee flexion at heel strike and greater peak hip adduction in runners with ITBS. Very limited evidence revealed higher peak ankle eversion in runners with PF and PTTD or higher peak hip adduction in PT.
Significance: Peak rearfoot eversion was the only factor reported in all included LLTs; it is a significant factor in ITBS, PT and PTTD but not in AT and PF. More prospective studies are needed to accurately evaluate the role of kinematic risk factors as a cause of LLT. Taken together, addressing rearfoot kinematic and kinematic chain movements accompanied by peak eversion should be considered in the prevention and management of LLT.

1. Introduction

Running has quickly become the most popular way to participate in physical activity worldwide [1,2]. Although it has many positive effects on health, running is also accompanied by the development of overuse injuries, mainly to the lower extremity [3,4]. A recent systematic review reports that running related injury (RRI) rates, followed for a long period, are 31.3% in marathon runners, 77.4% in cross-country runners and 84.9% in novice runners [5]. It was also shown that 10.9% of novice runners, participating in a short-term running program, sustained a RRI [6].

A major part of RRI are lower limb tendinopathies (LLT). Tendinopathy is a common problem characterized by often chronic, localized and load-dependent tendon pain, loss of optimal function and tendon thickening [7]. It has a multifactorial etiology in which (over) load seems to play an important role [8]. A prospective study indicates that 32% of runners develop an overuse injury, 22% of which is Achilles tendinopathy (AT), 16% plantar fasciitis (PF), 13% patellar tendinopathy (PT), 7% iliotibial band syndrome (ITBS), and 42% other injuries [9].

Biomechanical abnormalities resulting in repetitive abnormal load to the tendon are considered to be associated with an increased risk of LLT. Actions of lower limb joints cause changes throughout the kinematic chain of the lower extremity during the running gait [10,11]. For instance, changes in frontal plane rearfoot angles involve the kinematic chain of the lower limb, leading to higher stresses on more proximal structures [12,13].

A systematic review indicated that retraining strategies targeting

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kinematic risk factors are effective in the improvement of symptoms in lower limb injuries [14]. However, knowledge of kinematic risk factors for specific LLT is needed to develop these retraining programs. Although some systematic reviews exist that focus on one particular type of tendinopathy [12,15–17], none of these reviews specifically focused on kinematic risk factors and quantitatively synthesized studies results in a meta-analysis, except with Aderem and Louw's study [17] investigating ITBS.

To the best of our knowledge, no systematic review with meta-analysis has been conducted that reviews kinematic risk factors in running-related LLT other than ITBS. The aim of this study therefore is to identify kinematic risk factors in the most common running-related LLTs. Specifically, we aim to compare kinematic data of injured runners to healthy runners and pool evidence with a meta-analysis (if applicable). Increased knowledge and more insight into these kinematic risk factors might support the development of successful preventive and management strategies for LLT. In the long run this will be helpful to all healthcare professionals involved in the management of injured runners.

2. Methods

This systematic review was reported in accordance with the Prisma guidelines for systematic reviews [18].

2.1. Search strategy

Individual electronic search strategies of PubMed, Embase and Web Of Science were formulated and conducted on 1 March 2018. The search strategy was updated on 1 December 2018. There were three headings to the search: 1. "running or jogging or runners"; 2. "tendinopathy or tendinosis or tendinitis"; and 3. "biomechanics or kinematics" (Supplementary material, Table S1). In order to conduct an elaborate search strategy, search strategies of related systematic reviews published were also checked. To ensure identification of all relevant studies, reference lists of appropriate narrative and systematic reviews were hand-searched.

2.2. Eligibility criteria

Studies with a cohort, case-control and cross-sectional design were included in this systematic review. Studies were eligible if they compared healthy male and/or female distance runners to an injured sample related to LLT. To be included, studies needed to assess kinematics during running either on a treadmill or over ground. Articles on sprinters, triathletes or military personnel and studies on the topics of surgery, treatment, rupture or tendinopathy associated with disease or medication were excluded.

2.3. Study selection

This systematic review followed the process as shown in Fig. 1. Abstract and full-text studies were separately evaluated by two reviewers (HW, SHM). Any disagreements about inclusion/exclusion were resolved through a discussion between the reviewers and in consultation with a third reviewer (JZ).

2.4. Quality assessment

All included studies were scored for quality assessment using 15 items extracted from a modified version of the Downs and Black Quality Index (DBQI) [19]. Two reviewers (HW, SHM) independently assessed each included study and came to an agreement on articles in which the independent assessments differed. Inter-rater reliability of each checklist item was evaluated using the percentage agreement.

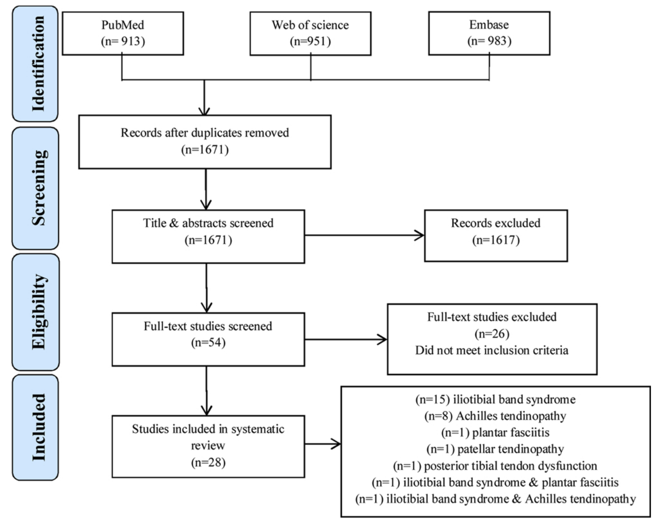

Fig. 1. Flow chart of study selection process.

2.5. Data collection

One author (SHM) extracted all relevant data from the included articles and all data were verified by HW in order to reduce bias and errors in data extraction. In this review, only the kinematic data commonly used in the management of injuries in the clinical setting were extracted, hence data for timing- and velocity-related parameters were excluded. Data were divided by type of tendinopathy into AT, ITBS, PF, PT and posterior tibial tendon dysfunction (PTTD) in order to maintain consistency in retrieval. General information on participant characteristics, measured variables, running mileage, speed, phase of the gait, diagnosis, gait analysis tool and test conditions were also extracted.

Mean differences and 95% confidence intervals (CI) were calculated using a random effects model in RevMan version 5.3. A meta-analysis was performed where studies investigated the same kinematic outcome measure with a comparable methodology for footwear and gender. The level of statistical heterogeneity for pooled data was established using I^2 statistics and associated P-values ($P < 0.05$). Results were reported by means of modified levels of evidence as defined by van Tulder et al. [20] (Table 1).

3. Results

Twenty five studies were included in the first search strategy conducted. Following an updated search strategy by 1 December 2018, 3 additional studies were eligible, resulting in twenty eight studies included in the final analysis. Details of the included studies are provided in Table 2. A total of seventeen studies investigated kinematic risk factors in runners with ITBS, nine investigated AT, two PF, one PT, and one investigated PTTD.

3.1. Methodological quality

Methodological quality assessment by means of the Downs and Black scale is presented in the Supplementary material, Table S2. The total scores ranged from 8 to 15 out of a possible 16. Quality assessment scores ranged from 56% to 94% (mean = 71%). Of the 28 prospective, case-control and cross-sectional studies, 18 studies were scored as HQ [9,21–37], ten as MQ [38–47]. Inter-rater reliability between reviewers was calculated using percentage agreement for all studies ranged from 88% to 100%, with a mean of 95%.

Table 1
Definitions of modified evidence levels [20].

Level of evidence	Description
Strong evidence	Pooled results from three or more studies, including a minimum of two high-quality studies which are statistically homogenous ($p > 0.05$) - may be associated with a statistically significant or non-significant pooled result.
Moderate evidence	Statistically significant pooled results from multiple studies, including at least one high-quality study, which are statistically heterogeneous ($p < 0.05$); or from multiple low- or moderate-quality studies which are statistically homogenous ($p > 0.05$); or statistically insignificant pooled results from multiple studies, including at least one high-quality study, which are statistically homogenous ($p > 0.05$).
Limited evidence	Results from multiple low- or moderate-quality studies which are statistically heterogeneous ($p < 0.05$); or from one high-quality study.
Very limited evidence	Results from one low- or moderate-quality study.
Conflicting evidence	Pooled results that are insignificant and from multiple studies, regardless of quality, which are statistically heterogeneous ($p < 0.05$, i.e. inconsistent).

3.2. Achilles tendinopathy

3.2.1. Characteristics of the included studies

Nine articles investigated kinematic data during running of runners with AT [9,23,24,29,31,32,34,40,44]. Eight articles evaluated these factors during the whole stance phase and one at 60% of stance phase. A total of 291 participants were analyzed. Five studies assessed kinematic data while running barefoot, three while running shod, and one while running both shod and barefoot. All subjects ran on a weekly plan ranging from 15 km/w to 97 km/w. Five studies assessed kinematic findings while running over ground at a speed between 3 and 4 m/s, four articles assessed while running on a treadmill at 2.4 m/s (barefoot), 2.8 m/s (shod) or a self-selected speed. Seven studies reported kinematic data on males and females; one study did not report gender and one study reported only on males. Six studies included participants with current symptoms, two with previous symptoms, and one study included participants who developed symptoms during follow-up. Three studies recruited participants with only mid-portion AT while others did not report the type of AT.

3.2.2. Kinematics of the ankle

The ankle kinematic outcomes of nine studies evaluating runners with and without AT are illustrated by a forest plot in the Supplementary material, Fig. S1. The meta-analyses assessing ankle kinematics risk factors are shown in Fig. 2A. Moderate evidence suggests significant difference for rearfoot eversion at heel strike (HS) in shod condition (mean 4.78, 95%CI 1.78,7.79) between runners with AT and controls. Strong evidence suggests no significant differences for peak rearfoot eversion in shod condition (mean 0.79, 95%CI −0.85,2.43), peak rearfoot eversion in barefoot condition (mean −0.17, 95%CI −1.74,1.40), peak ankle dorsiflexion in barefoot condition (mean −0.67, 95%CI −4.26,2.93) and shod condition (mean 0.5, 95%CI -1.75,2.75), and ankle dorsiflexion at HS in shod condition (mean 1.35, 95%CI −1.03,3.73) between runners with AT and controls. Moderate evidence suggests no significant differences between runners with AT and controls for the following variables: ankle plantar flexion ROM in barefoot condition (mean −0.84, 95%CI −3.45,1.78), ankle eversion ROM in shod condition (mean 2.17, 95%CI -2.11,6.44), and peak tibial internal rotation in bare foot condition (mean -0.95, 95%CI −2.07,0.17). There is conflicting evidence for ankle eversion ROM in barefoot condition (mean 0.59, 95%CI −2.29,3.47) and ankle dorsiflexion ROM in barefoot condition (mean 0.01, 95%CI −2.37,2.39) between runners with AT and controls.

3.2.3. Kinematics of the knee

The combined knee kinematic outcomes of nine studies evaluating runners with and without AT are illustrated by a forest plot in Supplementary material, Fig. S2. Results of meta-analyses for knee kinematics risk factors are shown in Fig. 2B. Moderate evidence suggests no significant differences between runners with AT and controls in the following variables: peak knee flexion in shod condition (mean −0.12, 95%CI -3.68,3.45), peak knee flexion in barefoot condition (mean −3.07, 95%CI –7.45,1.32), and knee flexion ROM in barefoot condition (mean 0.09, 95%CI −2.49,2.67). There is conflicting evidence for knee flexion ROM in shod condition (mean −1.68, 95%CI −6.75,3.38) and knee flexion at HS in shod condition (mean 0.04, 95%CI −4.10,4.19) of the AT group compared to the control group.

3.2.4. Kinematics of the hip

Limited evidence suggests that all hip kinematic variable comparisons between the AT and healthy groups were not significantly different (Supplementary material, Fig. S3).

3.3. Iliotibial band syndrome

3.3.1. Characteristics of the included studies

Seventeen articles investigated kinematic data of runners with ITBS during running compared with healthy runners [21,22,25–30,33,35–39,41,45,47]. Twelve studies evaluated kinematic data during the whole stance phase, 3 at 60% of stance phase, 1 by maximum excursion of angles at stance phase and 1 at full stride cycle. A total of 631 participants were analyzed. Fifteen articles assessed kinematic data of participants while running shod and two while running barefoot. All participants ran a weekly distance exceeding 15 km. Most of the studies assessed kinematic findings while running over ground at a speed between 3.3 and 3.7 m/s and seven articles while running on a treadmill at 2.23–3.3 m/s or a self-selected speed. Six studies reported data on females, eight reported on combined gender, two did not report gender, and one reported on males. One study compared the kinematic data of males to females, males to controls, and females to controls [27]. Ten studies included participants with current symptoms, five included participants with previous symptoms, one included patients with both current and previous symptoms, and one study included participants who developed symptoms during follow-up. One study investigated lower limb coupling variability between runners with ITBS and controls [38] (Supplementary material, Fig. S4).

3.3.2. Kinematics of the ankle

The combined ankle kinematic outcomes of studies evaluating runners with and without ITBS are illustrated by a forest plot in the Supplementary material, Fig. S5. Fig. 3A shows the possible meta-analyses suggesting moderate evidence with significant difference for decreased peak rearfoot eversion (mean −1.40, 95%CI −2.58, −0.23), strong evidence with no significant difference for peak rearfoot pronation (mean 1.47, 95%CI −0.05,2.99), and conflicting evidence for ankle flexion at HS (mean 2.09, 95%CI −2.86,7.03) between male/female runners with ITBS and controls.

3.3.3. Kinematics of the knee

The combined knee kinematic outcomes of studies evaluating runners with and without ITBS are illustrated by a forest plot in the Supplementary material, Fig. S6. Fig. 3B shows the results of the meta-analysis with strong evidence suggesting a significant difference in higher knee internal rotation (mean 2.90, 95%CI 1.20,4.59) of female runners, and moderate evidence with significant differences for decreased knee flexion at HS of male/female runners (mean -3.38, 95%CI −5.23, −1.53) and male runners (mean −2.73, 95%CI −5.03, −0.43) with ITBS and controls.

Table 2
Study characteristics.

Author	Study design	Population	Participants (m/f)		Age, yrs (SD)		Height, cm (SD)	
			injured	uninjured	injured	uninjured	injured	uninjured
Achilles tendinopathy								
Bramah et al., 2018 [29]	cross-sectional	runners	18(NR)	36(15 m,21f)	38.5(11.7)	33.2(8.4)	171.6(8.7)	171.6(7.3)
Creaby et al., 2017 [31]	cross-sectional	runners	14m	14m	43 (8)	37 (9)	179 (5)	177 (6)
Becker et al., 2017 [44]	cross-sectional	runners	9m, 4f	9m, 4f	37.6 (15.9)	32.6 (12.4)	NR	NR
Hein et al., 2014 [9]	prospective	recreational runners	10 (8 m, 2f)	10 (8 m, 2f)	45 (5)	40 (7)	177 (4)	177 (5)
Azevedo et al., 2009 [32]	cross-sectional	runners	21 (16 m, 5f)	21 (16 m, 5f)	41.8 (9.7)	38.9 (10.1)	177.8 (7.4)	174.3 (8)
Ryan et al., 2009 [34]	cross-sectional	runners	27 NR	21 NR	40 (7)	40 (9)	181 (7)	177 (7)
Donoghue et al., 2008 [40]	cross-sectional	runners	11(10 m, 1f)	11 (10 m, 1f)	39.6 (7.7)	45.2 (8.1)	175 (5)	177 (5)
Williams et al., 2008 [23]	retrospective cohort	runners	8 (6 m, 2f)	8 (5 m, 3f)	36 (8.2)	31.8 (9.3)	176 (7)	170 (10)
McCrory et al., 1999 [24]	cross-sectional	runners	31	58	38.4 (1.8)	34.5 (1.2)	174.5 (1.35)	174.5 (91.04)
Iliotibial band syndrome								
Bramah et al., 2018 [29]	cross-sectional	runners	18(NR)	36(15 m,21f)	34.3(7.9)	33.2(8.4)	170.6(8.5)	171.6(7.3)
Luginick et al., 2018 [28]	cross-sectional	recreational runners	30(15f, 15 m)	30(15f, 15 m)	f 40.6(7.61) m 36.6(8.76)	f41.5(7.96) m38.4(10.6)	f161(5) m176(5)	f163(6) m176(5)
Baker et al., 2018 [47]	cross-sectional	runners	15(7f,8 m)	15(7f,8 m)	f33.43(5.91) m32.75(6.09)	f31.43(7.5) m31.13(6)	f167(7) m181(5)	f168(6) m181(7)
Brown et al., 2016 [36]	cross-sectional	runners	12f	20f	32.4 (7.9)	28.9 (6.1)	170 (6)	160 (9)
Foch et al., 2015 [21]	cross-sectional	runners	9f current ITBS, 9f previous ITBS	9f	26.2 (7.9) cITBS, 24.7 (5.2) pITBS	25.3 (7)	164 (4) cITBS, 168 (3) pITBS	171 (5)
Phinyomark et al., 2015 [27]	cross-sectional	runners	48 (29 m, 19)	48 (29 m, 19)	34 (8)f, 39 (11)m	35 (8)f, 39 (12)m	169 (6)f, 179 (7)m	168 (6)f, 180 (6)m
Noehren et al., 2014 [30]	cross-sectional	runners	17 m	17 m	33.5 (6.6)	28.1 (5.7)	179 (6)	180 (7)
Foch & Milner, 2014 [33]	cross-sectional	runners	17f	17f	26 (6.6)	25.4 (6.2)	167 (5)	167 (6)
Foch & Milner, 2014 [37]	cross-sectional	runners	20f	20f	26 (5.6)	23.7 (5.5)	167 (4)	168 (6)
Ferber et al., 2010 [26]	cross-sectional	runners	35 f	35 f	35.47 (10.35)	31.23 (11.05)	165 (6)	167 (7)
Grau et al., 2011 [39]	cross-sectional	runners	18 (13 m, 5f)	18 (13 m, 5f)	36 (7)	37 (9)	177 (8)	177 (9)
Grau et al., 2008 [22]	cross-sectional	runners	18 (13 m, 5f)	18 (13 m, 5f)	36 (7)	37 (9)	177 (8)	177 (9)
Miller et al., 2008 [38]	cross-sectional	recreational runners	8 NR	8 NR	27.5 (9)	26.4 (7.7)	170 (6)	172 (8)
Noehren et al., 2007 [45]	prospective	runners	18 f	18 f	26.8	28.5	NR	NR
Miller et al., 2007 [35]	cross-sectional	runners	8 NR	8 NR	27.5 (9)	26.4 (7.7	170 (6)	172 (8)
Messier et al., 1995 [25]	case-control	runners	56 (76% m)	70 (59% m)	33.9 (1.2)	35 (1.2)	170.59 (13.7)	174.37 (10.7)

(*continued on next page*)

Table 2 (*continued*)

Author	Study design	Population	Participants (m/f)		Age, yrs (SD)		Height, cm (SD)	
			injured	uninjured	injured	uninjured	injured	uninjured
Messier & Pittala, 1988 [41]	case-control	recreational & competitive runners	13 f&m	19 f&m	NR	NR	NR	NR
Plantar fasciopathy								
Messier & Pittala, 1988 [41]	case-control	recreational & competitive runners	15 f&m	19 f&m	NR	NR	NR	NR
Pohl et al., 2009 [43]	cross-sectional	runners	25 F	25 F	31 (10)	31 (10)	166 (6)	167 (7)
Patellar tendinopathy								
Grau et al., 2008 [42]	cross-sectional	runners	12 F	12 F	40	39	167	168
Posterior tibial tendon dysfunction								
Rabbito et al., 2011 [46]	case-control	recreational runners	12 (3 m, 9f)	12 (3 m, 9f)	30.3 (7.9)	28.5 (8.6)	168.2 (10.8)	170.1 (7.8)

Author	Weight, kg (SD)		Running distance (km/w)		Injury situation	Speed	Running condition	Tool	Phase of running
	injured	uninjured	injured	uninjured					
Achilles tendinopathy									
Bramah et al., 2018 [29]	63.1(11.8)	60.8(8.4)	51(28)	97(37)	curr symp	3.2 m/s	Running on treadmill, own running shoes	3D motion analysis	stance
Creaby et al., 2017 [31]	82.3 (11.1)	73.5 (8.6)	38.1 (13.2)	35.9 (13.6)	curr symp	4 m/s	Running on 25 m walkway, standardized footwear	3D motion analysis	stance
Becker et al., 2017 [44]	NR	NR	50.1 (15.1)	52.3 (14.7)	curr symp	self-selected	Running around short track, own running shoes	3D motion analysis	stance
Hein et al., 2014 [9]	72 (8)	72 (8)	20 ≥	20 ≥	became symp during follow-up	3.33 m/s	Running on 13 m ethylene-vinyl acetate foam runway, barefoot	3D motion analysis	stance
Azevedo et al., 2009 [32]	77.6 (12.6)	70.2 (10.9)	15	15	curr symp	self-selected	Running on 10 m pathway, standard natural running shoe	3D motion analysis	stance
Ryan et al., 2009 [34]	78 (11)	71 (9)	30 ≥	30 ≥	curr symp	self-selected	Running on 13 m padded runway, barefoot	3D motion analysis	stance
Donoghue et al., 2008 [40]	71.9 (7.3)	77.9 (11.6)	NR	NR	curr symp	self-selected	Running on treadmill, barefoot and shoes	3D motion analysis	stance
Williams et al., 2008 [23]	67.3 (11.4)	65.6 (13.5)	41.3 (20.8)	35.3 (21.1)	curr symp	3.35 m/s	Running 20 m over ground, barefoot	3D motion analysis	stance
McCrory et al., 1999 [24]	71.43 (91.74)	70.03 (1.27)	52.1 (4.68)	44.5 (2.65)	curr symp	self-selected	Running on treadmill, shoes with that subjects became injured	3D motion analysis	Stance
Iliotibial band syndrome									
Bramah et al., 2018 [29]	63.6(11.2)	60.8(8.4)	24(9)	97(37)	curr symp	3.2 m/s	Running on treadmill, own running shoes	3D motion analysis	stance
Luginick et al., 2018 [28]	f55.43(6.3) m76.59(8.78)	f54.41(2.97) m72.23(5.46)	20 ≥	20 ≥	curr symp	self-selected	Running on 15 m runway, own running shoes	3D motion analysis	stance
Baker et al., 2018 [47]	f62.77(8.9) m78.25(7.4)	f65.94(7.8) m7.11(11.4)	16 ≥	16 ≥	curr symp	2.74 m/s	Running on treadmill, own running shoes	3D motion analysis	stance

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Table 2 (*continued*)

Author	Weight, kg (SD)		Running distance (km/w)		Injury situation	Speed	Running condition	Tool	Phase of running
	injured	uninjured	injured	uninjured					
Brown et al., 2016 [36]	60.6 (5)	56.8 (5.2)	24 ≥	24 ≥	curr symp	3.35 m/s	Running their own shoes 30 m runway, neutral running shoe	3D motion analysis	stance
Foch et al., 2015 [21]	53.3 (3.7) cITBS, 61.7 (9.9) pITBS	59.6 (5.2)	35.2 (18.7)	45.2 (22.5)	curr + prev symp	3.5 m/s	Running on 17 m runway, neutral running shoes	3D motion analysis	stance
Phinyomark et al., 2015 [27]	61 (9)f, 79 (10)m	62 (7)f, 81 (8) m	NR	NR	curr symp	self-selected	Running on motorized treadmill, shoe	3D motion analysis	full stride cycle
Noehren et al., 2014 [30]	76.7 (5.7)	69.9 (8.7)	31.4 (21.7)	30.8 (17.9)	curr symp	3.3 m/s	Running on instrumented treadmill, own running shoes	3D motion analysis	stance
Foch & Milner, 2014 [33]	57.9 (3.9)	58 (4.6)	44.9	44.7	prev symp	3.5 (0.18) m/s	Running on 17 m runway, neutral running shoes	3D motion analysis	stance
Foch & Milner, 2014 [37]	58.8 (7.4)	58.9 (5.7)	41.8 (25.1)	38.6 (18.2)	prev symp	3.5 m/s	Running on 17 m runway, neutral running shoes	3D motion analysis	stance
Ferber et al., 2010 [26]	58.62 (3.97)	61.30 (6.97)	123.82 (62.64) km/m	119.27 (52.02) km/m	prev symp	3.65 m/s	Running on 25 m runway, neutral running shoes	3D motion analysis	stance
Grau et al., 2011 [39]	71 (12)	70 (10)	20 ≥	20 ≥	curr symp	3.3 m/s	Running on 13 m EVA foam runway, barefoot	3D motion analysis	stance
Grau et al., 2008 [22]	71 (12)	70 (10)	NR	NR	curr symp	3.3 m/s	Running on 13 m EVA foam runway, barefoot	3D motion analysis	stance
Miller et al., 2008 [38]	68.7 (15.9)	71.3 (14.4)	NR	NR	prev symp	Self-selected	Running on treadmill, their own shoes	3D motion analysis	full stride cycle
Noehren et al., 2007 [45]	NR	NR	96.2 km/m	99.3 km/m	became symp during follow-up	3.7 m/s	Running on 25 m runway, standard neutral running shoes	3D motion analysis	stance
Miller et al., 2007 [35]	68.7 (15.9)	71.3 (14.4)	38 (24.3)	19 (9.5)	prev symp	Self-selected	Running on treadmill, their own shoes	3D motion analysis	stance
Messier et al., 1995 [25]	66.4 (1.9)	70.2 (1.3)	16 ≥	16 ≥	curr symp	Self-selected	Running on treadmill, their own shoes	2D motion analysis	stance
Messier & Pittala, 1988 [41]	NR	NR	74	77	curr symp	self-selected	Running on treadmill, training shoes	2D motion analysis	
Plantar fasciopathy									
Messier & Pittala, 1988 [41]	NR	NR	83.7	77	curr symp	self-selected	Running on treadmill, training shoes	2D motion analysis	
Pohl et al., 2009 [43]	61.6 (6.2)	64.3 (8.7)	40 (11)	42 (13)	prev symp	3.7 m/s	Running on 25 m runway with standard, neutral, and laboratory running shoes	3D motion analysis	stance
Patellar tendinopathy									
Grau et al., 2008 [42]	59	60	NR	NR	curr symp	3.3 m/s	Running on 13 m EVA foam runway, barefoot	3D motion analysis	stance
Posterior tibial tendon dysfunction									
Rabbito et al., 2011 [46]	65.7 (11.5)	68.9 (12.8)	NR	NR	curr symp	NR	Running on treadmill, barefoot	Pedar -X system	stance

Abbreviations: m male, f female, yrs years, cm centimeters, kg kilograms, km kilometers, h hour, m meters, s second, NR not reported, prev previously, curr currently, symp symptomatic.

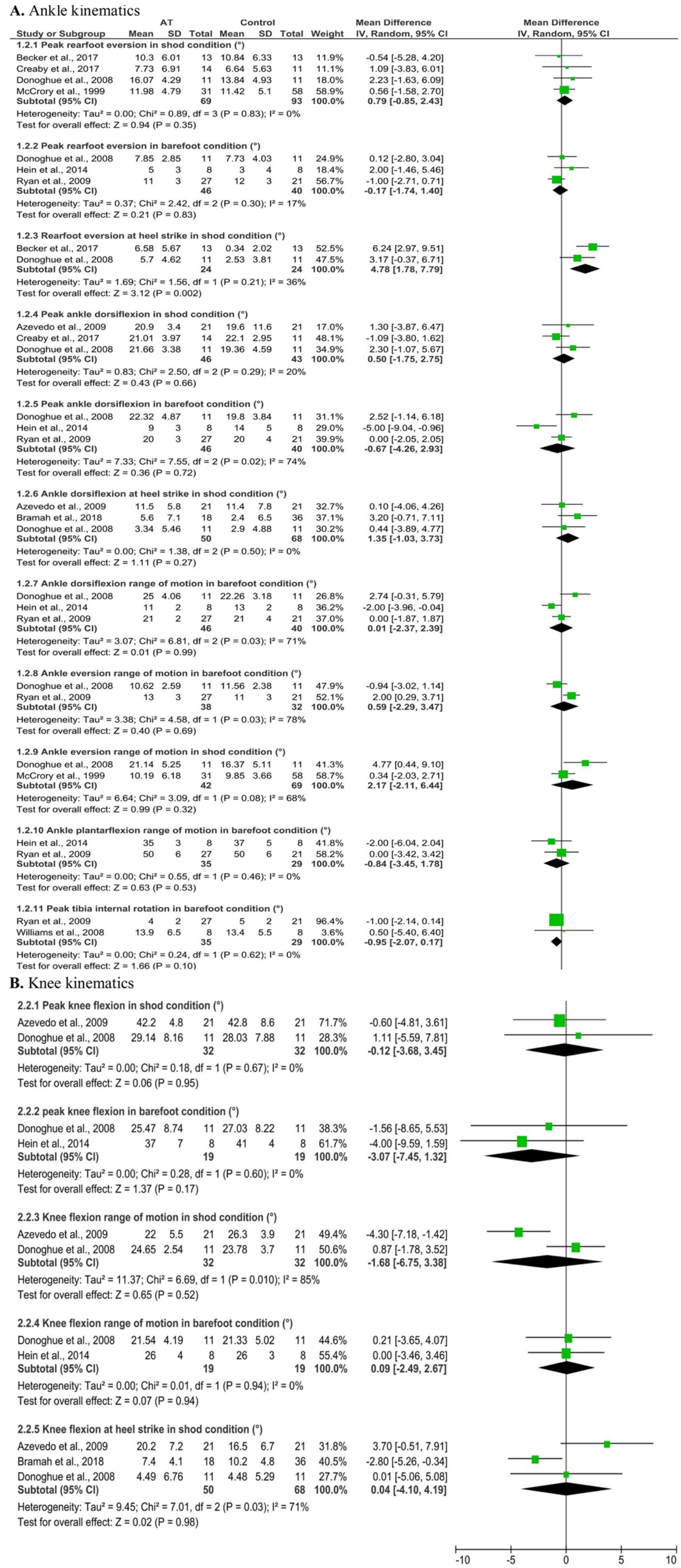

Fig. 2. Meta-analyses of AT kinematics.

3.3.4. Kinematics of the hip

The combined hip kinematic outcomes of studies evaluating runners with and without ITBS are illustrated by a forest plot in the Supplementary material, Fig. S7. Fig. 3C shows the results of the meta-analyses with conflicting evidence suggesting for peak hip adduction (mean 0.36, 95%CI −1.19,1.92), and moderate evidence with no significant difference for peak hip internal rotation (mean −1.96, 95%CI –6.00,2.08) between female runners with ITBS and controls. Moderate

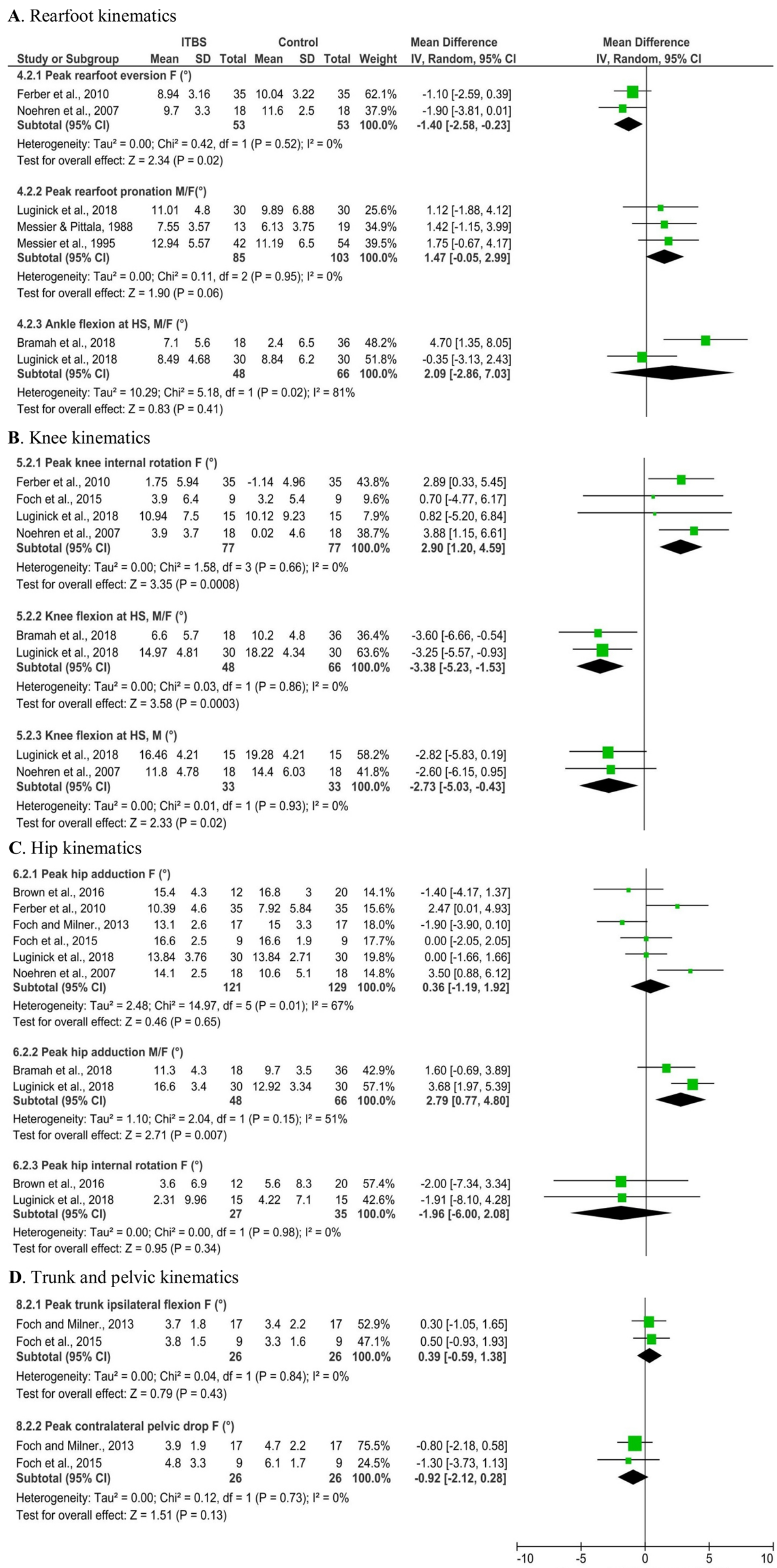

Fig. 3. Meta-analyses of ITBS kinematics.

evidence suggests a significant difference for increased peak hip adduction (mean 2.79, 95%CI 0.77,4.80) between male/female runners with ITBS and controls.

3.3.5. Kinematics of the trunk and pelvis

The combined trunk and pelvis kinematic outcomes of two studies evaluating runners with and without ITBS are illustrated by a forest plot in the Supplementary material, Fig. S8. Fig. 3D shows the results of the meta-analyses with moderate evidence suggesting no significant difference for peak trunk ipsilateral flexion (mean 0.39, 95%CI −0.59,1.38) and peak contralateral pelvic drop (mean -0.92, 95%CI −2.12,0.28) between female runners with previous ITBS and controls.

3.4. Plantar fasciopathy

3.4.1. Characteristics of the included studies

Two moderate-quality articles investigated kinematic data of runners with PF compared with healthy runners [41,43]. A total of 84 participants were analyzed. They evaluated kinematic data during the whole stance phase, one in a combined-gender population running on a treadmill with training shoes at subjects' average training speed [41] and the other in a female population running over ground with standard running shoes at a speed of 3.7 m/s [43]. There were no significant differences in evaluated kinematic factors (Supplementary material, Fig. S9).

3.5. Patellar tendinopathy

3.5.1. Characteristics of the included study

One cross-sectional moderate-quality study investigated hip, knee and ankle joint kinematics of female runners with PT during running compared with healthy female runners [42]. Twenty four participants were analyzed. The study evaluated kinematic data while running barefoot over ground during the whole stance phase at a speed of 3.3 m/s. The kinematic variables reported for PT show that peak ankle eversion and peak hip adduction were significantly higher in the PT group compared to controls. Tibial internal/external rotation ROM was significantly lower in the PT group compared with controls. There were no significant differences in the other kinematic variables evaluated in this study (Supplementary material, Fig. S10).

3.6. Posterior tibial tendon dysfunction

3.6.1. Characteristics of the included study

One case-control moderate-quality study investigated rearfoot kinematics in a mixed-gender population of runners with PTTD compared with healthy runners during the whole stance phase of walking barefoot on a treadmill at a self-selected speed [46]. Twenty four participants were analyzed. It was shown that peak rearfoot eversion was significantly higher in the PTTD group, with no significant differences in the other variables (Supplementary material, Fig. S11).

4. Discussion

Peak rearfoot eversion was the most pronounced risk factor for ITBS, PT and PTTD but not for AT and PF. A graphical abstract of the important kinematic factors based on the results of the meta-analyses is shown in Fig. 4. Proper understanding of such risk factors can potentially help coaches and clinicians improve prevention and clinical management of LLT in runners.

4.1. Achilles tendinopathy

4.1.1. Ankle kinematics

The only difference between runners with AT and controls was found in rearfoot eversion at HS. Runners with AT had greater rearfoot eversion. Evidence for this finding was moderate. For none of the other kinematic variables of the ankle a difference was found. This is in contrast with current information, popular beliefs and some AT-related studies claiming that abnormal alignment of the lower limb, especially in the lower leg, plays an important role in the development of AT [48–52]. As mentioned in the literature, excessive rearfoot eversion, mostly accompanied by an internally rotated tibia [53], causing excessive forces on the Achilles tendon, may predispose runners to AT [52]. However, the majority of pooled eversion-related kinematic variables did not show significant differences between AT and controls. The hypothesis that excessive eversion can be involved in the development of AT has led many researchers to evaluate the different features of foot pronation or eversion [24,31,34,40]. Most of the studies found no significant differences in pronation-related kinematic measurements; however, a trend of greater peak eversion was shown overall. Results also indicate that footwear control leads to different results for peak eversion; this indicates an increasing trend of peak eversion while running shod [31,40], in contrast to a decreasing trend of peak eversion while running barefoot [34,40].

4.1.2. Knee kinematics

It has been proposed that increasing the knee flexion angle is a shock-absorbing mechanism that serves to reduce loads on the lower extremity [54,55]. In this theory, an increase in knee flexion reduces peak vertical ground reaction impact force, potentially reducing the risk of AT. This is not supported by the pooled data from our study as no significant difference for knee-related kinematics between runners with and without AT was reported. Another theory that could play a role is that those with a higher risk of AT use a more natural or barefoot running style, which may imply a lower knee flexion with increased plantar flexion, resulting in higher Achilles tendon loads [56], as a

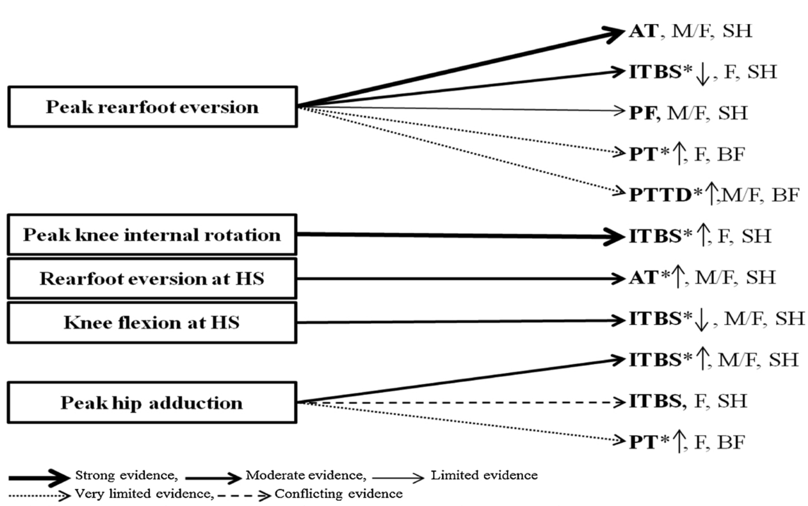

Fig. 4. A graphical abstract of important kinematic factors based on the meta-analyses results.

result of which the meta-analysis shows a trend toward lower knee flexion in AT group.

4.2. Iliotibial band syndrome

4.2.1. Ankle kinematics

A significant difference in lower peak rearfoot eversion in female runners with ITBS compared with healthy controls was found. This observation is consistent with lower peak tibial internal rotation being coupled to rearfoot eversion, as reported by two studies [22,45]. The result of the meta-analysis for peak pronation also shows a tendency toward higher peak pronation in runners with ITBS. These observations suggest that in participants who exhibit such kinematic chain disorders follow a distal mechanism for developing ITBS.

4.2.2. Knee and hip kinematics

Significant differences in knee flexion at HS and Peak hip adduction in runners with ITBS compared with healthy controls were found. However, evidence regarding peak hip adduction in female runners with ITBS compared with healthy controls was conflicting. It is suggested that ITB strain increases with excessive hip adduction and knee internal rotation because of the distal attachments of the ITB to the tibial condyle [45]. Moreover, some studies suggest that higher peak hip adduction in females is a major etiological factor for ITBS [26,45,57,58]. It is evident that hip abductor weakness, which leads to an increase in hip adduction [59], is associated with ITBS in distance runners in three out of five studies included [60]. Therefore, according to the prospective study and moderate evidence of two studies [45], still, greater hip adduction can be seen as etiological risk factors in the development of ITBS, plus greater knee internal rotation as shown in our study.

4.2.3. Pelvic and trunk kinematics

The results from our meta-analyses demonstrate no significant differences in peak trunk ipsilateral flexion and peak contralateral pelvic drop in female runners with previous and without ITBS. Nevertheless, it is assumed to be true that trunk and pelvic alignments are subject to ITB function, in which either ITB tightness may result in greater trunk lateral flexion or trunk lateral flexion during stance phase may be causing ITB tightness, resulting in a greater tensile strain of the ITB [33,35,61]. According to this theory, a recently published study revealed that greater contralateral pelvic drop is a contributing factor for classifying healthy runners not only with injured runners with ITBS but also runners with patella femoral pain, AT, and medial tibial stress syndrome [29]. Therefore, trunk motion might be important when managing ITBS. However, the results of this study could not be involved in the meta-analysis as subjects were a mix of male and female.

4.3. Plantar fasciopathy

No differences were found in ankle and rearfoot kinematic factors among subjects with and without PF [41,43]. It is believed that reduced ankle dorsiflexion in subjects with PF is compensated by increasing rearfoot eversion. Included studies reported no significant differences in rearfoot eversion between runners with PF and controls. It could be due to the similarity seen in ankle dorsiflexion between groups. It appears though that greater rearfoot eversion, accompanied with lower medial longitudinal arch, shifts the center of pressure to more medial and leads to increased plantar fascia tension [62]. Altogether, PF kinematics are most likely influenced by foot kinematics which cannot be analyzed with the kinematic models describing the foot as one rigid segment.

4.4. Patellar tendinopathy

While the kinematic risk factors are considered to be predisposing factors in the development of PT, only one study was found reporting kinematics of runners who developed PT [42]. Peak ankle eversion had a significantly greater magnitude in PT subjects, but interestingly, the author reported that the amount of pronation does not play a role in the development of PT. Despite eversion, being usually coupled with tibial internal rotation [63,64],– surprisingly – a higher peak ankle eversion with reduced tibial internal rotation as well as reduced tibial internal/external ROM were noted in PT subjects. It was believed that the mechanism transferring foot eversion into internal tibial rotation may be important to knee injuries [65]. Hip adduction, which can be considered as a pronation/tibial internal rotation coupling in the lower extremity kinematic chain [63,66,67], was significantly higher in subjects with PT compared to controls.

4.5. Posterior tibial tendon dysfunction

Very limited evidence suggests higher peak eversion in runners with PTTD relative to controls. Previous studies found that medial longitudinal arch angle and rearfoot and forefoot kinematics are contributing factors in predisposing individuals to PTTD [68–71]. The simulated results of a study on 22 cadaveric feet show that flat foot deformity and increased peak eversion may increase the effect of PTT friction [72]. It has been shown that when stage I PTTD is lasting and progresses into stage II, the medial and plantar elements of the foot such as the deltoid and spring ligaments work inefficiently, resulting in increased rearfoot eversion as well as decreased foot arch [73].

4.6. Limitations and research implications

The results of this study should be interpreted with some caution. Only two prospective studies, investigating the development of AT and ITBS, were included in this review. Most studies had a cross-sectional design because of which it remains unclear whether kinematic differences cause the injury or are a result of the injury.

There was a great variety of diagnostic methods in the included studies and AT studies did not differentiate between insertional and midportion AT. A clear description and definition of symptoms and duration of injuries is recommended for future studies.

Because of few studies investigating runners with PT, PF and PTTD, and most studies including mixed-gender groups, drawing of firm conclusions is hampered for part of the comparisons.

The PF studies considered foot kinematics as one rigid segment while PF relevant kinematics should be derived using multi-segment foot kinematics as the plantar fascia attaches to the rearfoot, forefoot and toes. Future studies should focus on more sophisticated models, like the Oxford foot model, to analyze other PF relevant kinematics (e.g. medial arch, hallux extension, important for the windlass mechanism).

This study highlights rearfoot eversion as a contributor factor to the LLTs. However, various methods were utilized to measure rearfoot eversion in the included studies. It could be confusing especially when studies apply various terms for rearfoot eversion explanation such as rearfoot pronation [41], pronation [25], calcaneus valgus [40] and ankle eversion [74]. Therefore, a well-suited biomechanical models such as Oxford foot model for calculating and distinguishing these terms is recommended.

4.7. Clinical implications

The results stress the need for controlling rearfoot eversion, which is most likely accompanied by proximal changes in the relevant kinematic chain of the lower extremity, as a potential management strategy for LLT. In a meta-analysis [75], interventions such as foot orthoses, motion control shoes and therapeutic taping were found to be effective in reducing rearfoot eversion in healthy and injured populations. Clinicians may apply these interventions to control rearfoot eversion when managing runners with LLT.

It is also proposed that clinicians consider potential interventions for modifying abnormal hip adduction in order to obtain more efficient results in the management of runners with ITBS. Possible conservative interventions to control abnormal hip adduction include gait retraining [76–79], foot orthoses [80,81], exercise approaches [82–84], gluteal strengthening [57,85], and femoral rotational taping [86]. These interventions have been shown to be effective in modifying increased hip adduction in lower limb injuries and might be helpful toward controlling increased hip adduction when managing ITBS too. Likewise, foot orthoses, which have been shown to be effective in reducing knee internal rotation in healthy [81] and patellofemoral pain syndrome individuals [80], might be effective in controlling knee internal rotation when managing ITBS. Increasing cadence and modifying foot strike pattern could be useful in controlling knee flexion [87].

5. Conclusion

Peak rearfoot eversion was the only factor reported in all included LLTs; it is a significant factor in ITBS, PT and PTTD but not in AT and PF. Taken together, the findings of this systematic review might aid clinicians in preventive and therapeutic clinical decision-making where appropriate interventions can target the kinematic risk factors, potentially reducing pain and improving function of runners with LLT.

Conflict of interest

None.

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