Title: Is there a pathological gait associated with common soft tissue running injuries?

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ABSTRACT

Background: Previous research has demonstrated clear associations between specific running injuries and patterns of lower limb kinematics. However, there has been minimal research investigating whether the same kinematic patterns could underlie multiple different soft tissue running injuries. If they do, such kinematic patterns could be considered global contributors to running injury.

Hypothesis: Injured runners will demonstrate differences in running kinematics when compared to injury free controls. These kinematic patterns will be consistent amongst injury subgroups.

Study Design: Case- Control Study

Methods: We studied 72 injured runners and 36 healthy controls. The injured group contained four subgroups of runners with either patellofemoral pain, iliotibial band syndrome, medial tibial stress syndrome or Achilles tendinopathy (n = 18 each). Three-dimensional running kinematics were compared between injured and healthy runners and then between the four injured subgroups. A logistic regression model was used to determine which parameters could be used to identify injured runners.

Results: The injured runners demonstrated greater contralateral pelvic drop and forward trunk lean at mid-stance and a more extended knee and dorsiflexed ankle at initial contact. The subgroup ANOVA found these kinematic patterns were consistent across each of the four injury subgroups. Contralateral pelvic drop was found to be the most important variable predicting classification of participants as healthy/injured. Importantly, for every 1° increase in pelvic drop there was an 80% increase in the odds of being classified injured.

Conclusion: This study identified a number of global kinematic contributors to common running injuries. In particular, we found injured runners to run with greater peak contralateral pelvic drop and trunk forward lean, as well as an extended knee and dorsiflexed ankle at initial contact. Contralateral pelvic drop appears to be the variable most strongly associated with common running related injuries.

Clinical Relevance: The identified kinematic patterns may prove beneficial for clinicians when assessing for biomechanical contributors to running injuries.

Keywords: Running, kinematics, injury, gait

What is currently known about the subject:

- Previous research has demonstrated clear associations between specific running injuries and patterns of lower limb kinematics.
- Studies have found similar kinematic patterns that could underlie multiple different running injuries.
- There may be kinematic patterns that represent global kinematic contributors to running injury.

What this study adds to existing knowledge:

- The characteristics of increased contralateral pelvic drop, forward trunk lean and a more extended knee and dorsiflexed ankle at initial contact are associated with multiple common soft tissue running injuries.
- Contralateral pelvic drop was identified as the parameter most strongly associated with running injury.
- For every 1° increase in contralateral pelvic drop there was an 80% increase in the odds of being classified injured.
- This is the first kinematic study to identify a potential set of global kinematic contributors to running injury.

INTRODUCTION

Running is an increasingly popular method of physical activity, however it also poses a risk of injury to the musculoskeletal system. It has been reported that approximately 50% of runners become injured annually with 25% injured at any one time.[13] The majority of running related injuries are considered to be overuse injuries, with the most frequently injured sites including the knee, foot and lower leg, with incidence rates reported of around 50%, 39% and 32% respectively [46]. Less common injury sites include the ankle and lower back, as well as the hip and pelvis, with incidence rates ranging from 4% to 16%, 5% to 19% and 3 to 11% respectively[45]. Of all running related injuries, the most frequently cited injuries include patellofemoral pain, iliotibial band syndrome, medial tibial stress syndrome, Achilles tendinopathy, plantar fasciitis, stress fractures and muscle strains.[24, 44] Many of these injuries are known to have high reoccurrence rates, leading to a reduction or cessation of training in approximately 30 to 90% of cases.[47] The factors related to the development of running related injuries are multifactorial and diverse, however it is widely accepted that abnormal running kinematics play a role.[1, 7, 31]

There has been a large amount of research that has sought to identify the kinematic patterns associated with many common soft tissue running injuries, including medial tibial stress syndrome (MTSS)[26], patellofemoral pain (PFP)[32, 52], iliotibial band syndrome (ITBS)[31 12] and Achilles tendinopathy (AT)[39]. Interestingly, many of these studies have reported similar kinematic patterns to be associated with different running injuries. For example, increased hip adduction has been associated with PFP[32, 52] and ITBS[31 12] and increased hip internal rotation has been associated with PFP[41] and MTSS[26]. Research has also suggested that due to the kinematic coupling between the femur, knee and foot, increased hip adduction or hip internal rotation may contribute to greater rearfoot eversion [2, 27, 38]. Interestingly increased rearfoot eversion has been associated with injuries such as MTSS [3, 50] and Achilles tendinopathy.[39] This research suggests that there may be a number of similar kinematic patterns that could underlie multiple different soft tissue running injuries. It is possible that these patterns could lead to elevated stress on multiple anatomical structures leading to injury development at different areas. These kinematic patterns may represent global contributors to injury.

Recent research supports the idea of biomechanical parameters that could be considered global contributors to running injury. In a prospective study of 249 runners, Davis *et al*[7] reported that runners who went on to develop a range of different injuries, demonstrated significantly elevated vertical loading rates. While in a retrospective study which investigated runners with AT and MTSS, Becker *et al*[3] reported greater rearfoot eversion at late stance phase, to be a characteristic consistently associated with injury. Although these two studies provide preliminary evidence for the existence of global contributors to running injury, Davis *et al* [7] did not include kinematic data, while Becker *et al*[3] investigated only MTSS and AT. Therefore, further research is required to understand whether there are similar kinematic patterns that may underlie multiple different running injuries. This understanding would be invaluable to clinicians as it could be used as a basis for both screening techniques as well as preventative and rehabilitative programs.

The aim of this current study was to identify whether there are kinematic parameters that may represent global kinematic contributors to running injury. To achieve this objective, we sought to identify whether there are differences in running kinematics between a large group of runners with common running injuries (ITBS, PFP, MTSS and AT) compared to a healthy control group. We hypothesised that the pooled group of injured runners would demonstrate greater contralateral pelvic drop, hip adduction and rearfoot eversion angles when compared to injury free controls. We also hypothesised that these kinematic patterns would be consistent amongst injury subgroups.

METHODS

Participants

A total of 108 runners were enrolled in this current study, including 72 injured runners (28 males, 44 females) and 36 healthy controls (15 males, 21 females) matched for age, height and weight (Table 1). The injured group contained subgroups of 18 runners with PFP, ITBS, MTSS and AT (Table 2). These injuries were selected as they are cited as the most prevalent soft tissue overuse running injuries.[24] An a priori sample size calculation was conducted using data from a previous study reporting kinematic differences between healthy and injured runners.[32] Using g*power software, we calculated that we would need at least 98 people (65 injured) in order to detect an effect size of 0.75 with a power of 0.85 and a critical α = 0.01. Participants were recruited via poster advertisements at local running clubs and sports injury clinics. All participants provided written informed consent prior to participation and ethical approval was obtained via the local ethics committee.

	Healthy (n = 36)	Injured (n = 72)
Age (years)	33.2 (8.4)	34.8 (9.9)
Mass (kg)	60.8 (8.4)	63.4 (10.5)
Height (cm)	171.6 (7.3)	170.7 (8.6)
BMI ($kg.m^{-2}$)	20.6 (1.8)	21.7 (2.7)
Miles run per week*	60.5 (23.2)*	21.2 (13.1)*

Table 1: Mean (SD) participant characteristics. *indicates statistical significance at p = <0.01.

	PFP (n = 18)	ITBS (n = 18)	MTSS (n = 18)	AT (n = 18)
Age (years)	34.5 (9.4)	34.3 (7.9)	31.9 (9.7)	38.5 (11.7)
Mass (kg)	64.4 (9.6)	63.6 (11.2)	62.5 (10.1)	63.1 (11.8)
Height (cm)	173.5 (8.5)	170.6 (8.5)	167.3 (8.1)	171.6 (8.7)

BMI ($kg.m^{-2}$)	21.3 (1.9)	21.8 (3.3)	22.2 (2.3)	21.3 (2.0)
Miles run per week*	18.6 (6.9)	14.8 (5.8)	19.5 (12.2)	31.9 (17.6)*

Table 2: Mean (SD) injury subgroup characteristics. *indicates statistical significance at p = <0.01.

Inclusion/ Exclusion Criteria

Injured Group

The injured group included individuals with a current diagnosis of either PFP, ITBS, MTSS or Achilles tendinopathy. Injury diagnosis was confirmed following a physical examination by a qualified physiotherapist in accordance with previously published diagnostic criteria for PFP,[6] ITBS,[17] MTSS[54] and Achilles tendinopathy[22] (Supplementary File 1). All participants reported being able to run up to 10 minutes before the onset of pain and maximal pain during running greater than 3/10 on a numerical rating scale (0 = no pain, 10 = worst possible pain). Additionally, all participants reported they were not currently receiving medical treatment for their injury and that their pain had caused a restriction to their running volume and/or frequency for a minimum of 3 months. Previous research has reported training factors such as increases in weekly training volume, to increase the risk of injury. This is likely due to a sudden excessive rise in acute tissue stress on the musculoskeletal system, resulting in insufficient time for adaptive changes[33]. Therefore, in order to control for training errors as a cause of injury, participants were excluded if they reported an increase in weekly training volume of greater than 30% proceeding the onset of injury.

Control Group

Control participants were included if they reported running a minimum of 30 miles per week for the last 18 months with no reported injury. Participants were excluded if they reported any musculoskeletal ailment within the last 18 months that caused a restriction or cessation of running, or any need to seek advice from a health care professional. Additional exclusion criteria included previous history of overuse running injury, injury caused by another sport, previous spinal injury or lower limb surgery.

Procedures

Kinematic data were collected from all participants whilst running on a treadmill at 3.2m/s wearing their own running shoes. After a 5 minute warm up period, 30 seconds of kinematic data were collected using a 12 camera Qualysis Oqus system (240Hz). A total of nine anatomical segments were tracked following a previously published protocol by the same authors shown to have good to excellent repeatability.[28, 37] Segments included the thorax, pelvis and bilateral thigh, shank and foot segments. In addition, a further rearfoot segment was included using 3 non colinear markers attached to the heel of the participant's shoes. The foot segment was used to calculate sagittal plane ankle kinematics while the rearfoot segment was used to calculate frontal plane foot kinematics. Further details of the markers used to track each segment and the precise definition of the anatomical coordinate systems is provided in supplementary file 2 and described in previous publications.[14, 28, 37]

Raw kinematic data were low pass filtered at 10Hz. Intersegmental kinematics, along with the motions of the pelvis and thorax with respect to the laboratory system, were calculated using a six degrees of freedom model using the commercial software Visual 3D (C-Motion). Gait events were defined using a kinematic approach[20] and subsequently used to segment each kinematic signal into a minimum of 10 consecutive gait cycles. An ensemble average for each signal was created and selected kinematic parameters derived from the ensemble average curves. This latter processing was carried out using a custom Matlab script.

Data Analysis

A range of kinematic parameters at both initial contact and mid-stance were selected for analysis. Parameters at initial contact included sagittal plane angles of the trunk, pelvis, hip, knee and ankle as well as frontal plane angles of the trunk and rearfoot. Peak angles at mid stance included sagittal and frontal plane angles of the trunk, pelvis, knee and ankle and rearfoot as well as transverse plane angles of the hip and knee. Parameters were selected based on previous research reporting differences between injured and non-injured runners[39, 41, 52]. Peak angles at mid-stance were defined as the maximum joint angle between initial contact and toe off. Foot strike patterns of each group were determined based on the kinematic waveforms of the ankle joint. Where the ankle demonstrated an immediate movement into plantarflexion, participants were classified as having a rearfoot strike, participants demonstrating immediate ankle dorsiflexion were classified as a forefoot strike. The injured leg was analysed from the injured runners, right or left leg was analysed at random from the healthy runners in order to match the total distribution of right and left legs in the injured group.

Statistical Analysis

Participant characteristics were analysed using independent t-tests for the healthy versus injured group comparisons and a one-way ANOVA for the subgroup analysis (Table 1 & 2). Chi-squared tests were used to assess for differences in distribution of foot strike patterns between the groups. In order to identify possible global contributors to running injury we used a two-phased approach. Firstly, data from the injured group were pooled and kinematic parameters compared with those of the healthy group using an independent t-test. Secondly, for any variables found to be significant different following the injured versus healthy comparison, we assessed for subgroup differences between the four injury subgroups using a one-way ANOVA test and post hoc Least Significant Difference (LSD). In order to be considered a global contributor to running injury, we required a kinematic parameter to be consistent across the different injury groups. This ensured that differences observed in the pooled injury data, were not the result of large effects in one of the injury subgroups. Before analysis, all kinematic parameters were assessed for homogeneity of variance and normal distribution using Levine's test (p = >0.05) and Shapiro-Wilk (p = >0.05). Where assumptions were not met, an equivalent non-parametric test was used. In order to reduce the possibility of type I error, a critical $\alpha = 0.01$ was used for injured versus healthy comparisons. However, we used a critical $\alpha = 0.05$ for the subgroup ANOVA analysis, due to the smaller subgroup sample sizes. This was deemed appropriate given the smaller number of group comparisons and therefore lower likelihood of type I error.

In addition to calculating statistical significance for group comparisons, we also calculated effect sizes. For t-test comparisons, we used Cohen's D and interpreted an effect size of 0.2, 0.5 and 0.8 as small, medium and large respectively.[4] For the ANOVA comparisons, we used the Eta squared statistic (η^2 = SS between groups/ SS total) and interpreted effect sizes of 0.01, 0.09 and 0.25 as small, medium and large respectively.[4]

Finally, a forward stepwise binary logistic regression analysis was conducted in order to determine which kinematic parameters could predict classification into either the injured or the healthy group. Parameters identified to be significantly different between healthy and injured groups were considered for the regression model. Variables were excluded from the regression model if they were found to demonstrate differences between injury subgroups.

RESULTS

Injured versus Healthy

The pooled data showed the injured runners to land with significantly more knee extension and ankle dorsiflexion (Table 3, Figure 2). At mid-stance, the injured runners were found to have significantly greater forward trunk lean, CPD (Figure 1a) and hip adduction (Figure 1c & 3, Table 4). Large effect sizes of 1.37, 0.89 and 0.87 were observed for CPD, hip adduction and knee flexion at initial contact respectively (Table 3 & 4). Trunk forward lean at mid-stance and ankle dorsiflexion at initial contact demonstrated moderate effect sizes of 0.65 and 0.71 respectively (Table 3 & 4). Chi-squared tests found no significant difference in the distribution of foot strike patterns between the groups (p = 0.332). In the healthy group there was a total of 17 forefoot and 19 rearfoot runners. In the Injured group there was a total of 27 forefoot and 45 rearfoot runners.

Variable	Control	Injured	P-value	Effect Size
Trunk Forward Lean (^{o})	3.9 (2.9)	5.7 (3.9)	0.033	0.52
Trunk Ipsilateral Lean (^{o})	2.5 (1.8)	3.1 (2.2)	0.257	0.28

Pelvis Anterior Tilt (°)	5.9 (3.3)	7.0 (3.8)	0.132	0.32
Knee Flexion* (°)	10.2 (4.8)	6.0 (4.9)	<0.01*	0.87
Ankle Dorsiflexion* (°)	2.4 (6.5)	7.2 (6.9)	<0.01*	0.71
Rearfoot Inversion (°)	8.7 (6.1)	6.2 (4.5)	0.018	0.47

Table 3: Kinematic parameters at initial contact. Data represents angle at initial contact in degrees. * indicates statistical significance at p <0.01.

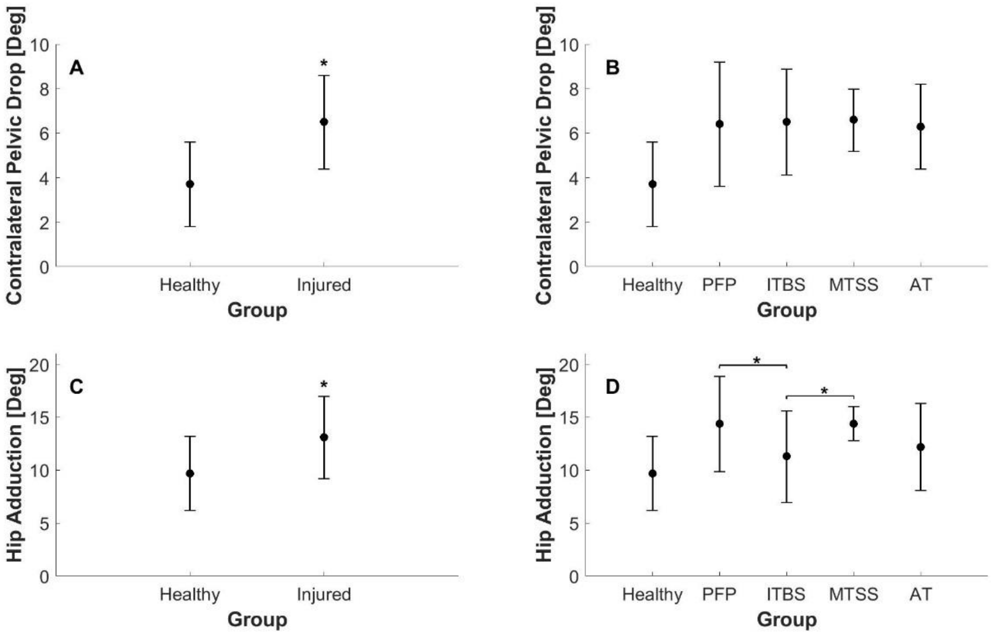

Figure 1: A: Contralateral pelvic drop for healthy and injured groups. B: Contralateral pelvic drop for healthy and injury subgroups. C: Hip adduction for healthy and injured groups. D: Hip adduction for healthy and injury subgroups. PFP = patellofemoral pain, ITBS = iliotibial band syndrome, MTSS = medial tibial stress syndrome, AT = Achilles tendinopathy. Whiskers represent +/- 1SD. * indicates statistically significant

differences for T-Tests (A & C) and subgroup ANOVA (B & D). Healthy group is shown in B & D for comparison purposes only.

Variable	Control	Injured	P value	Effect Size
Trunk Forward Lean* (°)	9.5 (2.9)	12.0 (4.9)	<0.01*	0.65
Trunk Ipsilateral Lean (°)	3.6 (1.8)	4.3 (2.6)	0.094	0.33
Pelvis Anterior Tilt (°)	5.0 (2.9)	5.7 (3.8)	0.553	0.19
Contralateral pelvic drop* (°)	3.7 (1.9)	6.4 (2.1)	<0.01*	1.37
Hip Adduction* (°)	9.7 (3.5)	13.0 (3.9)	<0.01*	0.89
Hip internal rotation (°)	4.4 (6.8)	4.2 (8.0)	0.874	0.03
Knee Flexion (°)	32.7 (4.9)	32.3 (5.0)	0.556	0.09
Knee Adduction (°)	-1.9 (3.1)	-2.0 (3.5)	0.785	0.06

Knee External Rotation (^{o})	6.7 (5.5)	7.1 (6.9)	0.616	0.06
Ankle Dorsiflexion (^{o})	22.3 (2.9)	21.9 (4.3)	0.964	0.09
Rearfoot Eversion (^{o})	2.6 (3.2)	4.0 (3.5)	0.047	0.42

Table 4: Peak kinematic angles during stance phase. Data represents maximum joint angle between initial contact and toe off. * indicates statistical significance at p <0.01.

Injury Subgroups

The subgroup ANOVA analysis was conducted in order to identify if there were differences between injury subgroups for variables identified as being different between the pooled injured and healthy groups. This analysis found no differences for ankle dorsiflexion and knee flexion at initial contact (Table 5). Furthermore, there were no differences in peak trunk forward lean and CPD during mid-stance (Table 5), indicating these parameters were consistent across the injury subgroups. However there was a significant difference between injury subgroups for peak hip adduction (Table 5). Post hoc LSD tests found the PFP (p = 0.018) and MTSS (p = 0.016) groups to have 3.1^{o} and 3.2^{o} more hip adduction than the ITBS group (Figure 1d).

	PFP	ITBS	MTSS	AT	ANOVA Between Injury Groups	Effect Size Eta Squared (η^2)

Initial Contact						
Knee Flexion (°)	5.5 (4.6)	6.6 (5.7)	4.7 (5.2)	7.4 (4.1)	0.365	0.05
Ankle Dorsiflexion (°)	10.6 (3.9)	7.1 (5.6)	5.5 (9.2)	5.6 (7.1)	0.088	0.09
Mid Stance						
Trunk Forward Lean (°)	11.9 (5.1)	14.3 (5.5)	10.9 (4.9)	11.3 (3.4)	0.160	0.07
Contralateral Pelvic Drop (°)	6.4 (2.8)	6.5 (2.4)	6.6 (1.4)	6.3 (1.9)	0.986	0.002
Hip Adduction* (°)	14.4 (4.5)	11.3 (4.3)	14.4 (1.6)	12.2 (4.1)	0.032*	0.12

Table 5: Between injury subgroups ANOVA. * indicates statistical significance at p <0.05

Logistic Regression

The final variables identified as global kinematic contributors included knee flexion and ankle dorsiflexion at initial contact as well as trunk forward lean and CPD at mid-stance. All four variables were entered into the logistic regression model. The forward stepwise logistic regression model identified that CPD at mid-stance (OR = 1.87; 95% CI: 1.41, 2.49; p = <0.001) and knee flexion at initial contact (OR = 0.87; 95% CI: 0.78, 0.97; p = 0.012) were significant predictors of classification as either healthy or injured, explaining 47% of the variance in the data (R^2 = 0.466). The most important predictor variable was CPD, with an

80% increase in the odds of being classified injured for every 1° increase in pelvic drop. For knee flexion there was a 23% reduction in the odds of being classified injured for every 1° increase in knee flexion at initial contact.

DISCUSSION

This study identified a number of kinematic differences between the injured and healthy runners that were consistent across injury subgroups. In particular the injured runners were found to demonstrate significantly greater peak contralateral pelvic drop (CPD) and forward trunk lean, as well as a more extended knee and dorsiflexed ankle at initial contact (Table 3, 4 & 5) (Figures 2 & 3). We found CPD to be the most important predictor variable when classifying runners as healthy or injured. These kinematic patterns may represent global kinematic contributors to soft tissue running injuries and together may define a pathological running gait.

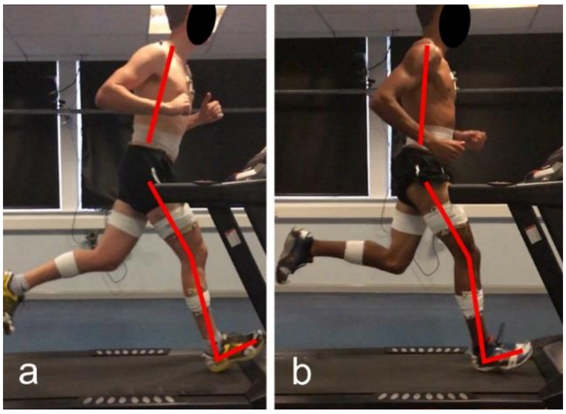

Figure 2: Two dimensional representation of forward trunk lean, knee flexion and ankle dorsiflexion angles at initial contact. A = injured runner, B = healthy runner.

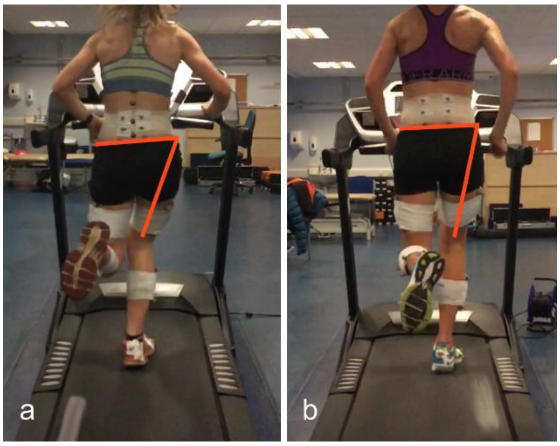

Figure 3: Two dimensional representation of contralateral pelvic drop and hip adduction during mid-stance. A = injured runner, B = healthy runner.

Global kinematic contributors

Peak contralateral pelvic drop was found to be the kinematic parameter most strongly associated with running injury. Previous studies have associated CPD with PFP[52] and MTSS,[26] however this study identified increased CPD amongst multiple different running related injuries, including ITBS and Achilles tendinopathy (Figure 1b). Therefore, CPD may represent a global kinematic contributor and risk factor for many common soft tissue running injures.

It is likely that CPD will influence lower limb tissue stress at a number of different anatomical sites through a number of different mechanisms. For example, Tateuchi *et al*[43] identified that increasing CPD resulted in an increase in iliotibial band tension at the lateral femoral condyle. This will likely influence ITBS development through increased strain rate [19] and increased compression between the ITB and lateral femoral condyle[11]. At the same time, an increase in ITB tension will result in a lateral displacement of the patella.[29] Lateral displacement of the patella will lead to a rise in patellofemoral joint stress, leading to PFP development,[36] while at the lower limb, increased CPD will result in a medial shift in the ground reaction force relative to the knee joint centre.[37, 42] This may alter the force distribution through the lower limb, leading to increased bending forces on the medial tibia[5] and potentially alter pressure distribution through the foot. This may contribute to the development of either MTSS or AT. [25, 50]

One possible explanation for the increased CPD observed in the injured group could be due to reduced strength or neuromuscular function at the hip. Previous authors have reported delayed onset of gluteus medius and maximus in runners with PFP[51] and AT[15], while others have reported reduced hip abductor strength in runners with ITBS[16], PFP[41], AT[18] and MTSS[48]. The hip abductors, in particular the gluteus medius, are thought to control frontal plane kinematics of the pelvis and hip[40]. Therefore, it is conceivable that reduced strength or neuromuscular function of the gluteus medius would lead to an inability to stabilise the pelvis in the frontal plane, causing increased CPD.

We also found the injured runners to land with greater knee extension and ankle dorsiflexion (Table 3, Figure 2), which may influence tissue stress in a number of ways. Firstly, in knee extension the patella becomes vulnerable to lateral tilt and displacement which may influence patellofemoral contact areas and joint stress during early stance[35]. Secondly, an extended knee and dorsiflexed ankle at initial contact is typically associated with a greater distance between the centre of mass and the foot at contact. Greater distance between the centre of mass and foot, as well as larger ankle dorsiflexion angles, have been associated with increased knee joint loading and breaking impulse[49]. An extended knee at initial contact has also been reported to reduce the ability to attenuate impact forces during early stance[8]. Collectively it seems plausible that the extended lower limb posture at initial contact may influence impact loading and knee joint loading during early stance.

One possible mechanism explaining the differences in forward trunk lean may be due to strength deficits around the gluteals and paraspinals. Previous studies have reported fatigue of the paraspinal and gluteal muscles to be associated with an increase in trunk forward lean during running[21] and drop landings[23]. Therefore, reduced strength capacity of the gluteals and paraspinals may result in an inability to maintain an upright running posture amongst the injured runners.

Kinematic Subgroups

While hip adduction was found to be greater amongst the pooled injured group, the subgroup analysis revealed this parameter differed across the injury subgroups (Table 5, Figure 1c & 1d). Specifically, we found hip adduction to be greater amongst subgroups of runners with PFP and MTSS compared to the ITBS subgroup (Figure 1d). This finding is in contrast to previous studies by Noehren et al[31] and Ferber et al [12] who reported increased hip adduction amongst runners with ITBS. One potential reason for the contrasting findings may be due to sex differences between studies. Hip adduction has been reported to be influenced by sex subgroups[52] with greater hip adduction amongst female runners. In the current study we included a mix of males and females while Noehren et al [31] and Ferber et al [12] only included female participants. While we acknowledge that hip adduction may be an important kinematic risk factor for certain injuries, we feel our data suggests hip adduction may be more influential in specific subsets of runners and pathologies, rather than others.

Limitations

One limitation is that the study was retrospective and therefore it is not possible to conclude if the observed kinematic patterns are the cause of injury, or the result of injury. Nevertheless, we ensured that all data were recorded before the onset of pain to minimise any possible effect of pain on the observed kinematic patterns. However we cannot rule out the possibility that participants may have adapted their running kinematics in response to chronic injury or in apprehension of the acute onset of pain. Therefore, we acknowledge that future prospective studies are required to further investigate whether the kinematic patterns observed within the current study are the cause or effect of injury. Another study limitation is the higher weekly mileage of the control group (Table 1). However, we feel that this could be considered a strength, as previous research suggests running greater than 40 miles per week is a risk factor for developing injury.[46] On average, our healthy control group were exceeding this threshold for more than 18 months prior to testing yet remained injury free. Therefore, we feel the control group may be representative of a healthy running gait in order to remain injury free at training loads exceeding the previously reported injury threshold. It is also important to note that this study was limited to a select number of common soft tissue running injuries and therefore these results may not apply to other injuries such as plantar heel pain, stress fractures and muscle strains. Further research would be required in order to establish a link between the identified kinematic patterns and other running related injuries.

Clinical Relevance

The findings from the present study may have a number of clinical implications. Firstly, all of the identified kinematic parameters can be easily visualised using two dimensional gait analysis methods[9, 10, 34] (Figures 2 & 3). A number of recent publications have shown 2D assessments of CPD, hip adduction, trunk forward lean and sagittal plane knee and ankle angles to be highly correlated with 3D measurement systems and to demonstrate high intra and inter-tester reliability [9, 10, 34]. Therefore, it should be possible to use 2D measurement techniques to assess the biomechanical parameters which were associated with injury in this study. Secondly, many of the identified global kinematic contributors to injury, can be modified through gait retraining. For example, CPD and hip adduction angles can be retrained using mirror feedback,[53] while knee and ankle angles are influenced by increasing cadence or modifying foot strike patterns.[30] Therefore, this study highlights a number of key kinematics that can be considered global contributors to running injury and can be easily assessed and modified in clinical practice. This may assist clinicians in the development of rehabilitation programs for common running related injuries.

CONCLUSION

This study identified a number of global kinematic contributors to common running injuries. In particular, we found injured runners to run with greater peak contralateral pelvic drop and trunk forward lean, as well as an extended knee and dorsiflexed ankle at initial contact. Contralateral pelvic drop appears to be the variable most strongly associated with common running related injuries. The kinematic patterns identified as global contributors to injury can be easily assessed and modified in clinical practice.

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