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A prospective study of gait related risk factors for exercise-related lower leg pain

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Abstract

The purpose of this study was to determine prospectively gait related risk factors for exercise-related lower leg pain (ERLLP) in 400 physical education students. Static lower leg alignment was determined, and 3D gait kinematics combined with plantar pressure profiles were collected. After this evaluation, all sports injuries were registered by the same sports physician during the duration of the study. Forty six subjects developed ERLLP and 29 of them developed bilateral symptoms thus giving 75 symptomatic lower legs. Bilateral lower legs of 167 subjects who developed no injuries in the lower extremities served as controls. Cox regression analysis revealed that subjects who developed ERLLP had an altered running pattern before the injury compared to the controls and included (1) a significantly more central heel-strike, (2) a significantly increased pronation, accompanied with more pressure underneath the medial side of the foot, and (3) a significantly more lateral roll-off. These findings suggest that altered biomechanics play a role in the genesis of ERLLP and thus should be considered in prevention and rehabilitation.

Keywords: Shin splints; Stress fractures; Plantar pressure; Kinematics; Alignment

1. Introduction

Exercise-related lower leg pain (ERLLP) is a common and enigmatic overuse problem in athletes and military populations [1]. Runners, track athletes and athletes participating in jumping sports are frequently diagnosed with ERLLP which is usually induced by repetitive tibial strain imposed by loading during intensive, weight bearing activities. A variety of categories can be labeled under this broad terminology of ERLLP and includes pathologies or terms such as shin splints, shin pain, medial tibial stress syndrome (MTSS), periostitis, compartment syndrome and stress fractures. However, the term ERLLP will be used in this paper as used by Brukner [2], as it adequately describes the clinicopathological features of the condition, while remaining appropriate for each term.

Generally, the most effective treatment for ERLLP is considered to be rest, often for prolonged periods [1]. This will significantly disrupt an active lifestyle, and sometimes end activity-related careers entirely. Therefore, analyses of risk factors for ERLLP are required as a prerequisite to the development of prevention programs.

Murphy et al. [3] recently reviewed the literature on risk factors for lower extremity injuries and demonstrated that our understanding of injury causation is limited. They concluded that more prospective studies are needed, emphasizing the need for proper design and sufficient sample sizes. In the literature, several aetiological factors have been suggested to induce ERLLP, which include in isolation or in combination, changes in training, activity type, intensity and frequency, footwear, and terrain as extrinsic (environmental related) risk factors [1,4]. As intrinsic risk factors, lack of running experience, poor

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physical condition, previous injury, decreased muscle strength, muscle fatigue, inflexibility, malalignment and adverse biomechanics have been quoted [1,4,5]. Retrospective studies have noted excessive dynamic foot pronation in subjects with a history of ERLLP [6,7]. In addition, static foot posture in subjects with ERLLP also showed a pronated foot alignment [8–10].

However, cross-sectional studies only allow clinicians to establish relationships but longitudinal prospective studies can investigate cause and effect relationships. Hitherto, no studies have been published on dynamic biomechanical intrinsic risk factors of ERLLP prospectively. The purpose of this prospective cohort investigation was to determine gait related risk factors for ERLLP in a young physically active population.

2. Materials and methods

2.1. Subjects

The subjects were 400 physical education students (241 men, 159 women; age range: 17–28 years; mean age: 18.4 ± 1.1 years), who were freshman in 2000–2001 (*n* = 121), 2001–2002 (*n* = 133) and 2002–2003 (*n* = 146) in Physical Education at the Ghent University, Belgium. All signed informed consent and the Ethical Committee of the Ghent University Hospital approved the study. Gait pattern and static alignment of the students were evaluated at the beginning of their education. Before testing, all students visited the same sports medicine physician for a comprehensive injury history. Exclusion criteria included a history of a surgical procedure involving the lower leg, ankle or foot, or history of an injury to the lower leg, ankle or foot within 6 months before the start of the study.

At the university level, the students followed the same sports program (Table 1) under the same environmental conditions, for 26 weeks per academic year. All students used the same sports facilities and the safety equipment was uniform. Extramural activities, being the amount of physical activities students participate in beyond their sports lessons at school were also registered.

Table 1
Weekly sports program in hours for physical education students at the Ghent University

	First year	Second year	Third year
Soccer	3/4	1	1/2
Handball	3/4	1	1
Basketball	3/4	1	1
Volleyball	3/4	1	1/2
Track and field	1	1	1/2
Gymnastics	1	11/2	1/2
Karate	1	1	–
Swimming	1	1	1/2
Dance	2	2	1
Climbing	–	1/2	–
Orienteering	–	–	1/2
Badminton	–	–	1
Judo	–	–	1

The students were followed weekly by the same sports physician for occurrence of injury throughout three, two and one academic years for freshman in 2000–2001, 2001–2002 and 2002–2003 respectively. They were asked to report all injuries resulting from sports activities during practice, lessons and games to this physician. The injury definition was based on that of the Council of Europe [11], which requires that an injury has at least one of the following consequences: (1) a reduction in the amount or level of sports activity, (2) a need for (medical) advice or treatment or (3) adverse social or economic effects. All injuries were medically assessed by the physician. When the diagnosis was not clear through this clinical assessment, x-ray, echography, bone scintigraphy (for diagnosis of stress fractures) or intracompartmental pressure measurement (for diagnosis of compartment syndrome) were performed.

2.2. Instrumentation and protocol

Before the start of their physical education, all students were tested for 3D kinematics combined with plantar pressure measurements during running and static lower leg alignment characteristics.

A footscan pressure plate (RsScan International, 2 m × 0.4 m, 16 384 sensors, 480 Hz) was mounted flush in the middle of a 16.5 m long wooden running track upon a 2 m AMTI-force platform. Video data were collected at 240 Hz using seven infrared cameras (Proreflex) and Qualisys software. Marker placement was based on that of McClay and Manal [12,13] (Fig. 1). This particular orientation enables the markers to define the anatomical coordinate system and to be used to track the motion of the segments [12]. Following a standing calibration trial, the subjects were asked to run barefoot at a speed of 3.3 m/s within a boundary of 0.17 m/s. After familiarisation, three valid left and three valid right stance phases were measured. A trial was considered as valid when the following criteria were respected: a heel-strike pattern, running speed within the outlined boundaries, and no visual adjustment in gait pattern to contact the pressure plate. Raw marker positioning was filtered with a second order, bidirectional low-pass Butterworth filter with padding point extrapolation with the reflected method. The cut off frequency was 18 Hz for the markers of the foot and the lower leg and 6 Hz for the markers of the thigh.

For each trial, eight anatomical pressure areas were semi-automatically identified, based on the peak pressure footprint (Fig. 2). These areas were medial heel (H_M), lateral heel (H_L), metatarsal heads I–V (M_1, M_2, M_3, M_4 and M_5) and the hallux (T_1) (heel areas: 2.1 cm × 1.5 cm; metatarsal areas and hallux: 1.4 cm × 1.0 cm). Peak pressure data, impulses (mean pressure × loaded contact time) and instants on which the regions make contact and end foot contact relative to total foot contact time were calculated for all eight regions. For each trial, besides the total foot contact time, five distinct instants of foot rollover were determined: first foot contact (FFC, instant the foot makes first contact with the pressure plate), first metatarsal contact (FMC, instant one of the metatarsal heads contacts the plate), forefoot flat (FFF, first instant all metatarsal heads make contact with the plate), heel-off (HO, instant the heel region loses contact with the plate) and last foot contact (LFC, last contact of the foot on the plate) [14]. Based on these instants, total foot contact could be divided into four phases: initial contact phase (ICP; FFC → FMC), forefoot contact phase (FFCP; FMC → FFF), foot flat phase (FFP; FFF → HO) and forefoot push-off phase (FFPOP; HO → LFC) [14]. A medio-lateral pressure ratio was calculated at these five instants of the foot contact (ratio = $[(H_M + M_1 + M_2) - (H_L + M_4 + M_5)]$/sum of pressure underneath all areas) [15]. Excursion range of this ratio was calculated over the four phases.

The *X*-component (medio-lateral) and *Y*-component (anterior–posterior) of the centre of pressure (COP) scaled to the foot width and foot length respectively were analysed (Fig. 3). The positioning and displacements of the components were calculated respectively at the five instants and during the four phases.

A multi-segment model was developed to calculate 3D joint coordinate system angles (Visual 3D, C-motion, USA). The three-dimensional motions of the knee and the ankle were investigated through positioning the lower leg segment with respect to the upper leg and the rearfoot with respect to the lower leg respectively. Joint rotation was calculated

Fig. 1. Marker placement based on that of McClay and Manal [12,13]. Retroreflective markers were placed on the upper and lower leg and on the rearfoot. The anatomical markers were placed on the greater trochanter, the medial and lateral femoral condyle, the medial and lateral malleolus, the medial and lateral part of the calcaneus and on the first and fifth metatarsal heads. The tracking markers consisted of a rigid plate secured to the thigh and the shank and the medial, lateral and upper calcaneus markers.

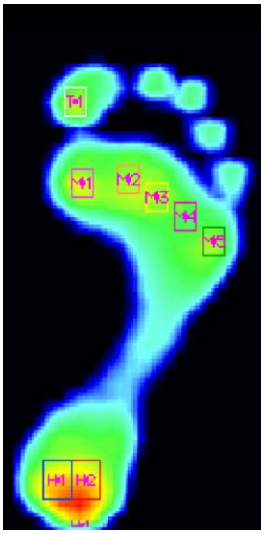

Fig. 2. The location of eight anatomical important areas on the peak pressure footprint. (Footscan software 6.3.4 mst, RsScan International) [14,15].

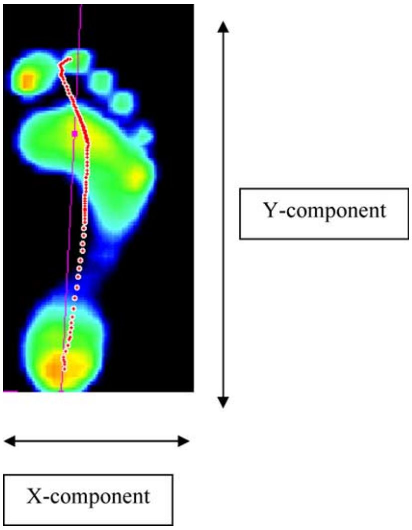

Fig. 3. The *X*-component (medio-lateral) and *Y*-component (anterior–posterior) of the COP. The *X*-component is positive when it is positioned medially of the heel-M2 axis and negative when it is laterally positioned. The *X*-component and *Y*-component were scaled to the foot width and foot length respectively. Foot width and foot length were defined on a separate static blueprint of the foot at the metatarsal heads and from heel to the furthest-reaching toe respectively [15].

around the plantar–dorsiflexion, inversion–eversion, abduction–adduction axes for the ankle and the flexion–extension, varus–valgus, internal–external rotation axes for the knee. All angles were referenced to standing. This study focused on the stance phase during running. Therefore, from the kinematic data, initial position at heel-strike, position at push-off, maximal position, excursion, maximal and mean excursion velocity were identified.

From all kinetic and kinematic data, mean of the three discrete variables of interest was calculated. Previous research has shown that for interpreting these data analysing the mean of three trials is sufficient [14,16,17].

Static lower leg alignment characteristics comprised manual goniometric talocrural plantar and dorsiflexion range with the knee straight and flexed [18], subtalar inversion and eversion [19], position of the calcaneus, unloaded and with the subtalar joint in neutral position and in stance with and without the subtalar joint in neutral position and flexion and extension range of motion at the first metatarsophalangeal joint [19]. Talocrural and subtalar goniometric measurements appear to be moderately to highly reliable [18,20]. Test–retest reliability of the goniometric measurements of the first metatarsophalangeal joint was good (intraclass correlation coefficients between 0.82 and 0.98 evaluated on 12 feet.).

2.3. Analysis

Statistics were performed using SPSS (version 11.0). The students were divided into two groups: an injury group with the injured legs of subjects who developed ERLLP and a control group of 167 subjects who did not have any injury of either leg during this study. Subjects who developed other injuries than ERLLP ($n = 187$) were excluded from the comparison. Firstly, a univariate Cox proportional hazard regression was used to test the effect of each variable on the hazard of injury, taking into account differences in the length of time that the subjects were at risk. Secondly, variables showing statistically significant association ($P < .05$) in the first analysis were entered into a multivariate forward stepwise Cox regression analysis to obtain a model for the prediction of ERLLP. This approach has been chosen because Cox regression can adjust for the fact that the amount of sport participation can vary between subjects. The primary outcome was the time from the start of the follow-up period until the first symptoms of ERLLP or the end of follow-up for students that were not injured. Time at risk was measured for each student as the total number of hours of sport exposure during sports lessons, practices for sports lessons, practices for recreational or competition sports and games until injury or, if uninjured, the end of the period students were followed. This analysis also took censorship into account, such as abbreviated length of follow-up for other reasons than injury (for example, not passing their academic course). The method assumed that risk factors affected injury in a proportional manner across time [21].

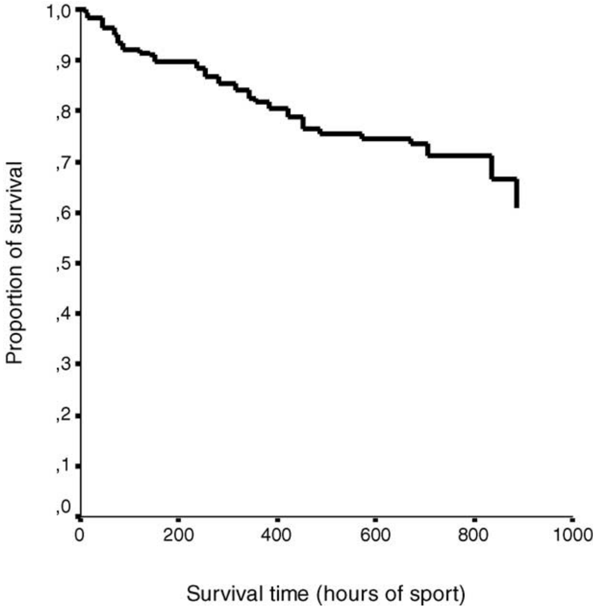

Fig. 4. Survival curve of the students for having exercise-related lower leg pain.

3. Results

During this study, 46 (11.5%, 17 males and 29 females) of the 400 subjects developed ERLLP. Twenty-nine developed bilateral symptoms. Consequently, the injury group comprised 75 symptomatic lower legs (35 left and 40 right). Fig. 4 displays the survival curve of the students for developing ERLLP.

Table 2 summarizes the significant results from the univariate Cox regression analysis. From all measured alignment characteristics, only extension range of motion at the first metatarsophalangeal joint was significantly different between groups. Analysis revealed that subjects who showed a higher extension range at the first metatarsophalangeal joint were at greater risk of ERLLP ($P = 0.002$).

Analysis of the pressure data showed that maximal peak pressure and impulse underneath M_5 is decreased in the injury group ($P = 0.006$ and $P = 0.011$ respectively). In the injury group, relative time of making contact was delayed in H_L ($P = 0.006$) and in M_5 ($P = 0.033$) and relative time of end of contact was delayed in M_2 ($P = 0.005$) and M_3 ($P = 0.032$). The medio-lateral pressure ratio showed that a higher pressure underneath the medial side of the foot at forefoot flat ($P = 0.003$) and heel-off ($P = 0.049$) and a greater displacement of the pressure from lateral to medial in the forefoot contact phase ($P = 0.001$) increased the risk of ERLLP. Analysis of the medio-lateral component of the COP revealed that subjects with a more medially directed COP at forefoot flat ($P = 0.039$) and a more laterally directed COP at last foot contact ($P < 0.001$) were at greater risk of ERLLP. During the forefoot contact phase there was less displacement of the COP to lateral ($P = 0.001$) and during the forefoot push-off phase there was more displacement to

Table 2

Mean and standard deviation for significant contributors for exercise-related lower leg pain by univariate Cox regression analysis for uninjured and injured subjects

	Uninjured	Injured	*P*-value
MTPIJ extension	70.89 ± 16.95	76.64 ± 15.22	0.002
Peak pressure M_5 (N/cm^2)	34.86 ± 18.85	26.88 ± 13.19	0.006
Impulse M_5 (N s/cm^2)	3.14 ± 1.82	2.41 ± 1.34	0.011
First contact H_L (%)	0.00 ± 0.04	0.04 ± 0.13	0.006
First contact M_5 (%)	9.12 ± 5.87	11.34 ± 10.43	0.033
End contact M_2 (%)	93.76 ± 3.82	95.38 ± 3.54	0.016
End contact M_3 (%)	91.29 ± 4.44	92.91 ± 4.13	0.032
Ratio FFF	−10.30 ± 24.10	1.54 ± 29.04	0.003
Ratio HO	14.12 ± 18.56	20.16 ± 18.28	0.049
Ratio FFCP	−9.77 ± 21.66	2.39 ± 26.12	0.001
X-component FFF (%)	−7.98 ± 6.91	−5.49 ± 4.66	0.039
X-component LFC (%)	10.30 ± 8.77	3.23 ± 8.59	<0.001
X-component FFCP (%)	−6.80 ± 5.81	−3.54 ± 4.55	0.001
X-component FFPOP (%)	18.71 ± 9.37	10.99 ± 8.54	<0.001
Y-component FFC (%)	8.45 ± 1.80	9.31 ± 5.36	0.007
Y-component LFC (%)	93.87 ± 4.45	91.28 ± 6.37	0.001
Excursion abduction (°)	11.43 ± 4.02	12.92 ± 4.88	0.026
Maximal abduction Vel (°/s)	353.66 ± 119.17	435.01 ± 173.52	0.001
Maximal eversion position (°)	7.66 ± 5.05	9.60 ± 5.81	0.034
Excursion eversion (°)	13.81 ± 4.39	15.47 ± 5.46	0.032
Mean eversion Vel (°/s)	114.92 ± 48.92	133.34 ± 54.87	0.034
Maximal eversion Vel (°/s)	381.28 ± 141.43	440.73 ± 195.42	0.031
Mean inversion Vel (°/s)	140.57 ± 76.03	173.56 ± 75.37	0.029

MTPIJ: metatarsophalangeal I joint, FFF: forefoot flat, HO: heel-off, FFCP: forefoot contact phase, LFC: last foot contact, Vel: velocity ratio = $[(H_M + M_1 + M_2) - (H_L + M_4 + M_5)] \times 100/\text{sum}$ of the pressure underneath all areas; a positive ratio indicates a medially directed pressure distribution, a negative ratio a laterally directed pressure distribution.

lateral in subjects susceptible to ERLLP ($P < 0.001$). Subjects who showed an increased distance of the anterior–posterior component of the COP at initial contact ($P = 0.007$) and a decreased distance at last foot contact ($P = 0.001$) were at greater risk of ERLLP.

Results of the Cox regression performed for 3D kinematics at the ankle showed that subjects of the ERLLP group had a significantly increased abduction excursion ($P = 0.026$) and accordingly increased maximal abduction velocity ($P = 0.001$), an increased maximal eversion ($P = 0.034$) and eversion excursion ($P = 0.032$) and accordingly increased mean and maximal eversion velocity ($P = 0.034$ and $P = 0.031$ respectively). Mean re-inversion velocity ($P = 0.029$) was also increased in these subjects. No significant differences were observed between the two groups for 3D kinematics at the knee joint.

Table 3 represents the risk model ($P < 0.001$) for the prediction of ERLLP as a result of a multivariate stepwise Cox regression analysis. The anterior–posterior component of the COP at first foot contact ($P = 0.087$), the medio-lateral ratio during the forefoot contact phase ($P = 0.007$) and the medio-lateral component of the COP at last foot contact ($P < 0.001$) were found to be the best predictors of ERLLP.

4. Discussion

The present investigation is the first study to determine dynamic biomechanical intrinsic risk factors of ERLLP prospectively. The overall incidence of ERLLP reported in our population (11.5%) is comparable with previous reports [8,22]. The increased incidence in women (18% versus 7% in men) is in accordance with other studies [8,10]. This study reveals that the running pattern of subjects who develop ERLLP differed from subjects who remained injury free. Summarized, these altered biomechanics include: (1) a central heel-strike at initial contact, (2) a more everted foot accompanied with a higher loading underneath the medial forefoot and less underneath the lateral forefoot during the forefoot contact and foot flat phases, and (3) an increased re-inversion velocity with an increased lateral roll-off and increased extension range of motion at the first metatarsophalangeal joint.

Kinematic variables and plantar pressure data showed the same trends of excessive eversion and an increased lateral roll-off in the running pattern of the subsequently injured subjects. Although plantar pressure variables were more discriminating between the injured and uninjured subjects, we chose for a functional division concerning content in which plantar pressure was combined with kinematic data and alignment.

The pathophysiology of medial tibial stress syndrome remains controversial. Some authors suggest an inflammation of the periosteum due to excessive traction (traction theory), others support the view that MTSS is not an inflammatory process of the periosteum, but rather a bone stress reaction (bone stress theory) as in stress fractures [23–25]. Although that MTSS and stress fractures constitute different pathologies, they sometimes coexist and it is likely that MTSS and stress fractures of the tibia are invoked by similar mechanisms, where MTSS is a relatively mild expression and stress fracture is a severe extreme [1]. The coincidence of the most common site of tibial stress fracture at or near the junction of the middle and distal thirds with the site of incidence of MTSS bolsters this suspicion [1].

Table 3

Risk model for the prediction of exercise-related lower leg pain versus no injury obtained by multivariate Cox regression

	B	S.E.	*P*-value	Hazard ratio	95% confidence interval
Y-component FFC	0.081	0.047	0.087	1.084	0.988–1.189
Ratio FFCP	3.762	1.400	0.007	43.047	2.769–669.275
X-component LFC	−0.134	0.038	<0.001	0.874	0.811–0.942

FFC: first foot contact, FFCP: forefoot contact phase, LFC: last foot contact, *B*: regression coefficient, S.E.: standard error.

The most striking result of this investigation was that an increased eversion increased the risk for ERLLP, which can be functionally linked with both theories. Several kinematic and plantar pressure parameters indicate this increased loading underneath the medial side of the foot and decreased loading underneath the lateral side in subjects with subsequent ERLLP: (1) first metatarsal contact was made with the fourth metatarsal head instead of with the fifth, (2) the peak pressure and impulse underneath M_5 were significantly lower, (3) the medio-lateral ratio indicated that pressure distribution was more medially directed at forefoot flat and heel-off and indicated a greater displacement of the pressure from lateral to medial in the forefoot contact phase, (4) the medio-lateral component of the COP was more medially positioned at forefoot flat and indicated less lateral displacement in the forefoot contact phase and (5) there was a higher eversion and abduction excursion in the rearfoot and accordingly increased eversion and abduction velocities in subjects susceptible to ERLLP.

Pronation is described as a triplanar motion consisting of the components eversion, abduction and dorsiflexion [26]. In a previous investigation, Engsberg indicated that in subjects with overpronation, dorsiflexion excursion during running was not increased, but eversion and abduction excursions were [27]. In our investigation, similar findings were observed since the dorsiflexion excursion was not significantly different between the groups, but eversion and abduction excursions were significantly increased in our injury group.

The results of this study confirm that overpronation and increased velocity of pronation was associated with an increased incidence of ERLLP as suggested before by many investigators [6,9,22,25,28–30]. However, this is the first study to demonstrate this prospectively. During running, pronation is necessary to dissipate stress. When the rearfoot everts, the foot becomes a more mobile adaptor that allows shock attenuation [31]. Because the rearfoot and the knee are mechanically linked by the tibia and because of the inclined axis of the subtalar joint in the sagittal plane, eversion in the foot normally leads to internal rotation at the knee [32,33]. However, in our study eversion and abduction at the rearfoot was increased in the injury group but the internal rotation at the knee was not increased. These motions could be absorbed by musculoskeletal structures in the lower leg itself. However, it is difficult to confirm this because of the high inter-subject variability in eversion-internal rotation ratio [33] and because of the use of external markers, which are not as accurate as bone pins. McKeag and Dolan [28] found that in runners who overpronated, the transmission of force up the leg was exaggerated resulting in excessive mid-tibial torsion stress following exaggerated internal rotation during the stance phase, which supports the 'bone stress theory'. On the other hand, excessive eversion may be associated with increased internal inversion moments as the invertor musculature attempts to control the motion. This may lead to excessive eccentric traction to the plantar flexor and invertor musculature which has their origin on the medial and posterior region of the tibia, and could be linked with the 'traction theory'. During running, each foot strikes the ground approximately 600 times per kilometer [34]. When each heel-strike then generates a strain on the mid-tibial musculoskeletal structures, the musculoskeletal system may become overloaded and overuse injury may occur.

The second identified characteristic of the gait in subjects susceptible to ERLLP was hitting the ground with the centre of the heel instead of with the posterior and lateral border of the heel in controls. This is indicated by the anterior–posterior component of the COP which was positioned further forward in the injury group compared to the control group. In addition, in the injury group, the medial and lateral heel areas made contact at the same time. In the control group contact was made first with the lateral heel area and then with the medial heel area, which indicated an early pronation. During this initial pronation, first shock absorption may take place. We suggest that in our subjects who developed ERLLP subsequently, this early pronation did not take place because of the central heel-strike. Therefore, shock absorption had to occur in the following pronation phase which will be exaggerated.

The third characteristic identified in subjects with subsequent ERLLP was an accelerated re-inversion with a more lateral roll-off. The more laterally situated position of the medio-lateral component of the COP at last foot contact and the more lateral displacements in the forefoot push-off phase also accorded with these findings and the end of contact of M_2 and M_3 was delayed. Thus, the final roll-off did not happen dominantly across the hallux as normal [35], but more laterally. This was probably caused by the diminished support at the first metatarsophalangeal joint, which showed a very mobile extension range of motion compared to the control group. During the re-inversion phase, bones of the midfoot become 'locked up', hence allowing the foot to become more stable to act as a rigid lever for push-off [31]. During the pronation phase an excessive eversion took place, which led to a less stable foot. To compensate for this excessive eversion, a greater and accelerated re-inversion could occur to provide the rigid lever for push-off.

It is possible that static lower leg alignment characteristics may directly influence ERLLP by altering the forces applied to the lower leg. In the literature, numerous variables have been assessed including range of rearfoot inversion–eversion, ankle dorsiflexion–plantar flexion and big toe flexion–extension. In the current study, we could not find a significant relationship between talocrural ranges of motion and ERLLP. Accordingly, most other investigations also failed to find a relationship [29,36,37], however in the study of Fredericson limited dorsiflexion had been associated with tibial stress fracture and MTSS [38]. In our study, all subjects had a normal dorsiflexion range of motion with a smallest range of 17°. Even this range falls within the normal ankle dorsiflexion range and this ankle was flexible enough to perform a normal running pattern in which 15° of dorsiflexion is regularly needed as seen in our population.

In contrast to the results of Viitasalo and Kvist [7], our results identified no association of subtalar range of motion or the position of the calcaneus with ERLLP. Viitasalo and Kvist reported greater subtalar eversion and inversion range of motion in their subjects with MTSS compared with controls. Subtalar ranges of motion in our subjects were in accordance with those reported by Viitasalo and Kvist [7] in their MTSS group. These values have been reported as normal in another study [39]. We therefore suggest that controls in the study of Viitasalo and Kvist [7] had probably a limited range of subtalar motion.

In the investigation of Engsberg [27] no relationship could be found between static ranges of motion in the ankle and the dynamic kinematic data obtained during running. During running several movement excursions were significantly greater than the static ranges of motion. Greater ranges of motion were probably produced by the externally applied torques that occurred during running [27]. In addition, static measures lack the component 'velocity of motion', which can be an indicator for strain rate and linked with injury. Thus, we emphasize the need for dynamic measurements in aetiological investigations for activity-related injuries.

Physical activity is mostly performed in shod conditions. However, the gait pattern in this study was measured during barefoot running which was for two reasons. Firstly, the purpose of this study was to determine gait related risk factors for ERLLP as *intrinsi*c risk factors for this injury. Shod conditions could have masked the intrinsic biomechanics at the foot. Secondly, running and jogging are not the only risk-bearing sports activities for ERLLP. Other types of sports in which ERLLP is frequently encountered, are performed barefoot, for example dancing and gymnastics. Therefore, in a broad population, such as physical education students, testing barefoot can be considered as a functional measurement.

A limitation in this investigation was the large amount of variables in our statistical analysis. This increased the risk for significances (type I error) and decreased the power. As we analysed our data in a large cohort and not at the individual level, we are aware that not every identified intrinsic risk factor was present in every subject who developed ERLLP. Some subjects who had an increased risk because of the presence of an intrinsic risk factor, but did not develop ERLLP.

5. Conclusion

This is the first prospective study that identified a central heel-strike, an excessive eversion and an increased lateral roll-off as risk factors for ERLLP. Prevention programmes should examine these parameters and adapt them to reduce the incidence of ERLLP. In addition, treatment of ERLLP should consider altering these parameters. In the literature, it has been suggested that orthotic inserts, taping and antipronation shoes can limit pronation [4,40,41] which may reduce the incidence, prevent exacerbation and assist in the recovery from ERLLP.

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