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Health Review

Biomechanical analysis of running: correlation between main frontal findings and foot and ankle injuries in amateur runners

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Abstract: To correlate the most prevalent ankle and foot injuries in amateur runners with the biomechanical analysis of running, considering the patterns of frontal analysis evaluated in a private orthopedic and physical therapy service. Retrospective analysis of 56 medical records of amateur runners with ankle and foot complaints who underwent biomechanical assessment of running in an Orthopedics and Physical Therapy clinic in 2017 and 2018. Lesions found: Shin splints (26.78%); plantar fasciitis (21.42%); Achilles tendinopathy (21.42%); Tibial Stress Syndrome (8.92%); lower limb stress fractures (5.35%); posterior tibial tendonitis (5.35%); peroneal tendinopathy and ankle sprain (7.14%); talar chondral lesion (1.78%) and Morton's neuroma (1.78%). The biomechanical analysis showed that the most common findings were valgus knees, with 43 cases (76.78%), followed by pelvic drop and center of mass vertical oscillation, with 40 cases each (71.42%) and hamstring retraction, with 37 cases (66.07%). Among the least prevalent, varus knees and supinated foot stand out, with two cases each (3.57%) and medial or lateral heel whip (5.35%, 3 cases). The most prevalent findings were valgus knee, pelvic drop, center of mass vertical oscillation, and hamstring retraction. Among the least present, stand out the varus knees, the supinated foot and the medial or lateral heel whip.

Keywords: Athletic Injuries; Running; Foot Injuries; Biomechanics.

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1. Introduction

Running is one of the most common and accessible physical activities. The easy practice, associated with its low cost, makes it economically accessible and, therefore, one of the best ways to reach the daily recommendations of physical activity recommended by the World Health Organization (WHO) [1]. However, injuries from the practice are also frequent. Running injuries, such as patellofemoral pain, iliotibial band syndrome, and stress fractures of the tibia and metatarsals have been identified as highly prevalent in runners [2].

Although injury-related factors are undoubtedly multifactorial, there is strong evidence that biomechanical factors in running play a key role in injury development. Recent studies have demonstrated biomechanical abnormalities in patients with running-related injuries [3-6]. In this context, the biomechanical analysis of running evaluates all the movements performed by the athlete during this exercise, observing mechanical imbalances that can cause abnormality in the running technique or, even, cause injuries, which can be treated and corrected before causing further damage. This analysis is performed with markers on the trunk, pelvis, legs, knees, and feet, which assess movements.

Understanding the mechanics of running is essential to bring about superior athlete performance. By identifying possible changes in movements, the professional can prevent several injuries and help the athlete to ensure better and better results.

In the present study, we analyzed the frontal plane of runners during running, considering the following variables: Plantar Flexor Muscle Strength Deficit, such as in Gastrocnemius and Soleus muscles, responsible for knee flexion and ankle plantar flexion; Core strength deficit, a set of muscles that stabilize the spine, pelvis and hip during movement; Pelvic Drop, a relationship that assesses the maximum pelvic obliquity during the stance phase of gait; Medial or Lateral Heel Whip, medial (Figure 1A) or lateral (Figure 1B) rotation of the foot in relation to the body's midline, occurring in the transition from stance to swing phase, known as "heel whip" (7), when absent, it is called neutral Heel Whip; Varus knees, in which the deviation is lateral in relation to the foot; Center of Mass Vertical Oscillation, defined as the vertical displacement of the trunk at each step; Cross Over Gait pattern, occurring when the step of one foot is just in front of the other in the frontal plane (8); Toe Out pattern, when there is external rotation of the foot at 30 degrees from the sagittal line; pronated and supinated foot, in which there is pronation during walking, or eversion of the foot, and foot supination or inversion, respectively. Runners who do not have a pronated or supinated foot are considered to have a neutral gait.

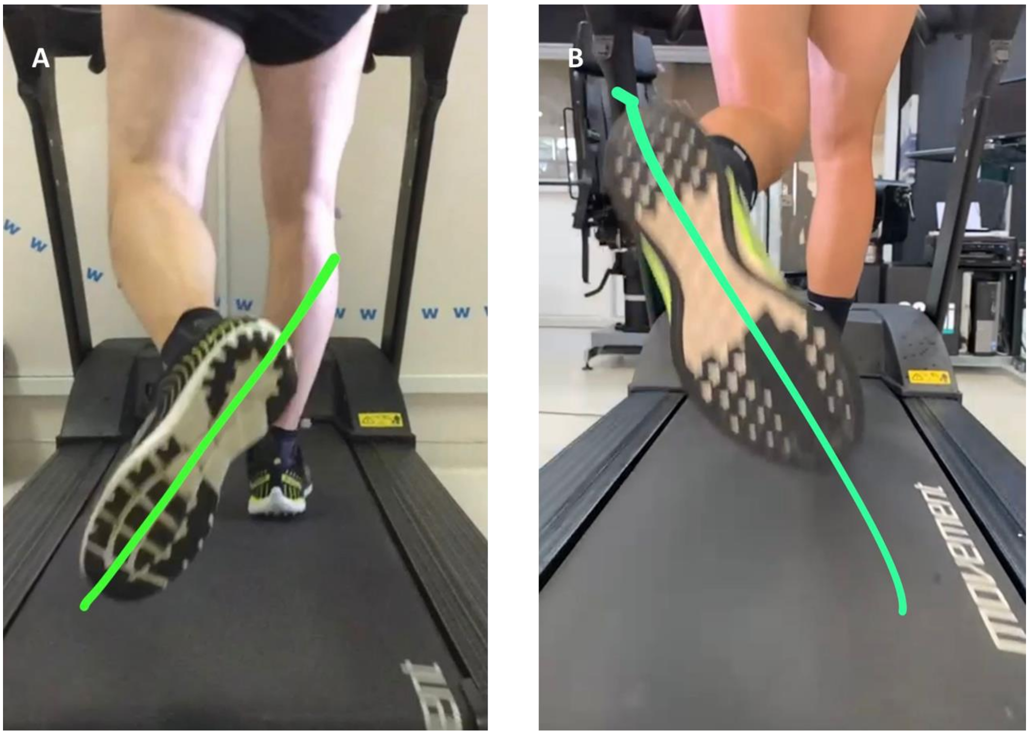


Figure 1: A. Medial heel whip. B. Lateral heel whip.

The objective of the present study was to correlate the most prevalent ankle and foot injuries found in amateur runners with the biomechanical analysis of running, considering the frontal plane analysis.

2. Material and Methods

This was a cross-sectional retrospective epidemiological study, carried out between 2017 and 2018 in a private clinic in Campinas, state of São Paulo, Brazil. Fifty-six runners with ankle and foot complaints were evaluated. Amateur runners over 18 years of age, both sexes, who sought the service with complaints of discomfort or pain in the musculoskeletal system were considered. Exclusion criteria were patients under 18 years of age; runners of less than 1 km per week and asymptomatic subjects.

A runner was defined as an individual who has run at least once a week for at least a month, with weekly mileage greater than or equal to one kilometer per week, regardless of experience (amateur, experienced, professional, etc.). In this evaluation, any changes and muscle deficits in the calf, knee, hip and core muscles (group of muscles that make up the center of the trunk, the kinetic chain that transfers strength to the limbs) were inspected to identify factors that may influence the runner's performance, being: sex, age, weight, height, cadence, weekly mileage covered, dominant side and affected side of the injuries.

All the variables of this study were obtained from medical records: age, sex, weekly mileage of the race, weight, height, cadence, type of injury and results of the biomechanical evaluation. The biomechanical assessment included analysis of the patient in the frontal plane, evaluating: Plantar Flexor Muscle Strength Deficit; Medial and Lateral Core Strength Deficit; Pelvic Drop; Medial or Lateral Heel Whip; Center of Mass Vertical Oscillation; Varus Knee; Valgus Knee; Cross Over Gait Pattern; Toe Out Pattern; pronated, supinated or neutral foot.

The biomechanical analysis of running took place in the Laboratory of Kinetics and Kinematics Evaluation, considering athlete's history, flexibility assessment, footprint analysis by computerized baropodometry, 2D kinematic analysis of foot, ankle, knee, hip and spine articulators during running detected by highly sensitive sensors, assessment of muscle performance by computerized isokinetic dynamometry and analysis of strength and muscular endurance of the core. Analyses are performed sequentially, carried out in approximately one hour and thirty minutes, with the issuance of the report in 48 hours.

This evaluation was carried out with a 2D analysis system, Full HD cameras, LED sources, ultrasensitive and retroreflective sensors, isokinetic dynamometer, and a state-of-the-art treadmill, Isokinetic Dynamometer (Cybex, Humac Norm model 770), Computerized Baropodometry (Loran Engineering), 2D Camera System -nMy Video Hd Noraxon, Thermographic Camera (Flir C2), iPad and Computer.

For data analysis, data on mean and standard deviation of age, weight, height, cadence and weekly mileage collected from the patients, were used to divide them into groups according to the diagnosis of the lesions found. From the diagnoses of the patients, it was correlated with the findings of the biomechanical analysis of running.

3. Results

Among the 56 evaluated runners, 24 were female (42.85%) and 32 were male (57.14%). Mean values and standard deviation of age, weight and height were38.91 ± 6.9 years, 72.19 ± 12.80 kg and 171.44 ± 8.84 cm, respectively. The mean weekly mileage was 27.43 km ± 16.52 km. Cadence had a mean of 169.67 and a standard deviation of ± 10.27.

The diagnoses of the lesions found in the analyzed patients were: shin splints (15 cases or 26.78%); plantar fasciitis (12 cases or 21.42%); Achilles tendinopathy (12 cases or 21.42%); Tibial Stress Syndrome (5 cases or 8.92%); stress fractures in the lower limbs (3 cases or 5.35% - 1 metatarsal, 1 tibia and 1 calcaneus); posterior tibial tendonitis (3 cases or 5.35%); peroneal tendinopathy and ankle sprain (4 cases or 7.14%); talar chondral lesion (1 case or 1.78%) and Morton's neuroma (1 case or 1.78%). Relationships of age; weight, height, mileage, and cadence are listed in table 1.

The most frequent findings in the biomechanical analysis of the 56 patients evaluated were valgus knees, with 43 cases (76.78%), followed by pelvic drop and center of mass vertical oscillation, with 40 cases each (71.42%) and hamstring retraction, with 37 cases (66.07%). Among the least prevalent, varus knees and supinated foot, with two cases each (3.57%) and medial or lateral heel whip, with three cases (5.35%). The relationships between the lesions and the findings in the biomechanical analysis are presented in table 2.

Table 1: Relations Between Evaluated Runners

	Age (years)	Weight (kg)	Height (cm)	Weekly mileage	Cadence (ppm)
Stress fractures in the lower limbs					
Mean	41.7	53.7	158.3	9.3	166.7
Standard deviation	3.7	3.1	3.9	7.4	9.4
Complex fracture of the calcaneus					
Mean	40.3	74.5	170.3	20.1	176.5
Standard deviation	7.7	10.0	5.9	16.7	10.7
Peroneal tendon injuries and ankle sprains					
Mean	40.8	64.0	166.8	22.3	175.3
Standard deviation	8.0	12.4	11.0	12.4	9.6
Talar chondral lesion					
Mean	31.0	80.0	182.0	32.5	182.0
Morton's neuroma					
Mean	40.0	69.0	160.0	30.0	172.0
Tibial stress syndrome					
Mean	36.6	75.6	173.4	37.0	168.4
Standard deviation	6.4	10.4	6.5	11.7	7.8
Posterior tibial tendonitis					
Mean	39.0	71.3	174.0	24.2	168.0
Standard deviation	2.2	15.5	5.2	17.8	8.6
Shin splint					
Mean	35.9	72.7	173.7	24.4	165.9
Standard deviation	6.2	12.1	8.6	11.8	6.5
Plantar fasciitis					
Mean	41.5	74.7	173.3	23.8	168.4
Standard deviation	6.3	13.5	9.2	22.2	12.6

4. Discussion

The evaluation of the correlation between biomechanical changes and injuries involved is valid to anticipate possible involvement. The Plantar Flexor Muscles, such as the

Gastrocnemius and Soleus muscles, are muscles responsible for knee flexion and ankle plantar flexion. In our study, the finding in the frontal plane analysis was found in small percentages, associated with Achilles tendinopathy and plantar fasciitis.

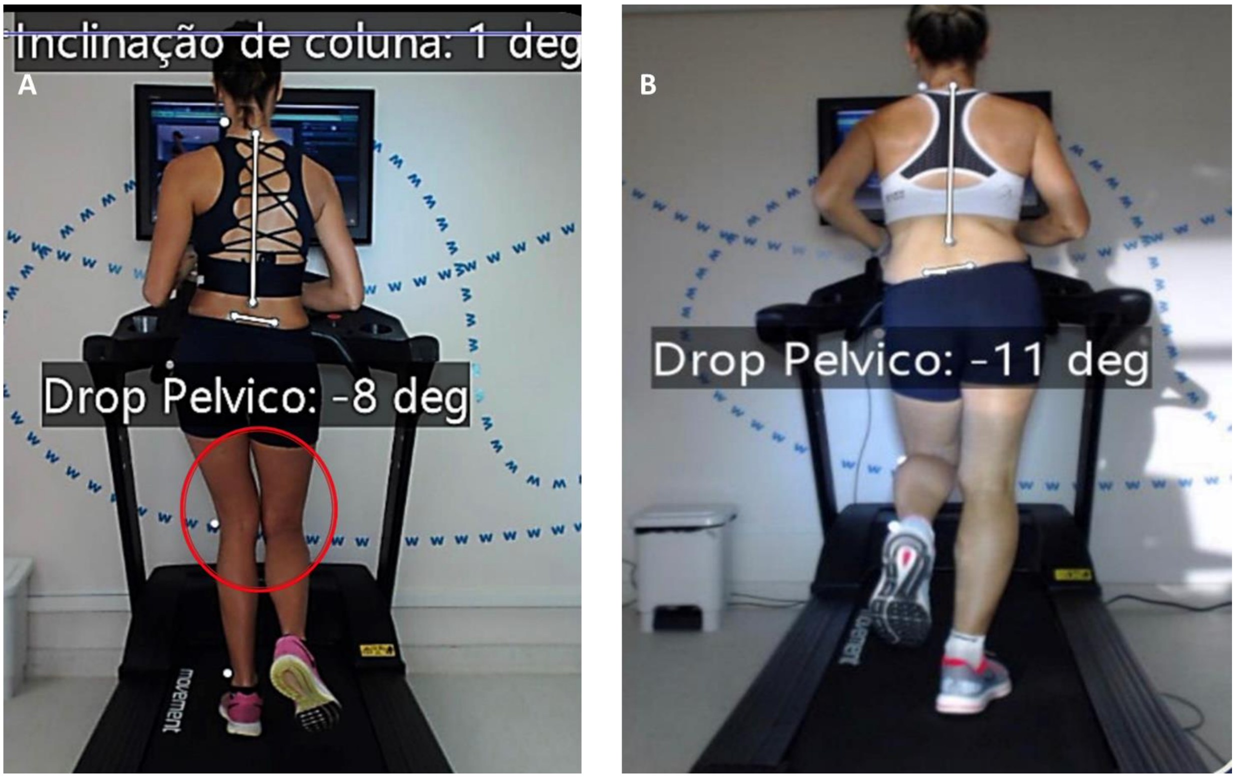
Table 2: Correlation Between Biomechanical Changes and Injuries Involved

	A	B	C	D	E	F	G	H	I	J	K	L
Stress fractures in the lower limbs (n=3)												
	0	3	1	3	0	1	0	1	0	0	0	0
	0%	100%	33%	100%	0%	33%	0%	33%	0%	0%	0%	0%
Calcaneal tendinopathy (n=12)												
	4	5	0	9	1	7	0	8	3	0	0	0
	33%	42%	0%	75%	8%	58%	0%	67%	25%	0%	0%	0%
Peroneal tendinopathy and ankle sprain (n=4)												
	0	2	0	3	0	4	0	3	2	0	0	0
	0%	50%	0%	75%	0%	100%	0%	75%	50%	0%	0%	0%
Talar chondral lesion (n=1)												
	0	1	0	1	0	1	0	1	0	0	0	0
Morton's neuroma (n=1)												
	0	1	0	1	0	1	0	0	1	0	0	0
Tibial stress syndrome (n=5)												
	0	1	3	5	4	3	0	3	0	0	0	0
	0%	20%	60%	100%	80%	60%	0%	60%	0%	0%	0%	0%
Posterior tibial tendonitis (n=3)												
	1	2	1	2	1	2	0	2	2	1	1	1
	33%	67%	33%	67%	33%	67%	0%	67%	67%	33%	33%	33%
Shin splint (n=15)												
Total = 15	2	11	2	10	0	13	1	12	11	0	1	0
	13%	73%	13%	67%	0%	87%	7%	80%	73%	0%	7%	0%
Plantar fasciitis (n=12)												
	4	5	3	7	1	10	1	8	5	2	2	1
	33%	42%	25%	58%	8%	83%	8%	67%	42%	17%	17%	8%

A. Plantar flexor muscle strength deficit. B. Lateral core strength deficit. C. Frontal core strength deficit. D. Pelvic drop. E. Medial oor lateral heel whip. F. Valgus knee. G. Varus knee. H. Center of mass vertical oscillation. I. Cross over gait pattern. J. Toe-out pattern. K. Pronated foot. L. Supinated foot.

The Pelvic Drop assesses the maximum pelvic obliquity during the stance phase of gait (Figures 2A and Figure 2B). Excessive drop during running contributes to excessive hip adduction, a variable that has been associated with numerous running injuries [9-12], such as Iliotibial Band Syndrome and Patellofemoral Pain Syndrome in the lower limbs. In our study, Pelvic Drop was present in most injuries described, especially Stress Fractures and Tibial Stress Syndrome, in which the finding was observed in 100% patients. The literature, however, lacks previous studies that address the relationship between Tibial Stress Syndrome and Stress Fracture with the finding of Pelvic Drop.

Figure 2: A. patient presenting Pelvic Drop of -8 deg on the right. B. patient presenting Pelvic Drop of -11 deg on the left.



Pronated foot is a variable that has received attention in runners [13, 14]. Several studies have associated pronated stride with various injuries in runners, such as Tibial Stress Fracture and Achilles Tendinopathy [15, 16]. However, in our study this relationship was not present. None of the patients studied with calcaneal tendinopathy had pronated foot, which was also not present in the patient with a stress fracture of the tibia. This can be explained by the difficulty in measuring the foot pronation of the runner in the 2D frontal analysis, so the literature suggests other indirect variables for the analysis, such as heel eversion [17]. On the other hand, supinated foot, which is characterized by the presence of stiffness in the medial longitudinal arch with calcaneal inversion and varus hindfoot [18], is related in the literature with plantar fasciitis and ankle injuries [19]. In the present study, there is a 33% relationship between runners with supinated foot and those affected with posterior tibial injury. Still, 8% had plantar fasciitis. Runners who did not have a pronated or supinated foot are considered to have a neutral gait.

Heel Whip is another common finding. In a previous study, the medial or lateral Heel Whip was found in 57% analyzed amateur runners [18], without necessarily being related to lower limb injuries. In our study, Heel Whip was present in 80% (4 of 5 patients) with Tibial Stress Syndrome, however, there is little or no literature that correlates the finding in the analysis of running and the observed injury.

Regarding the deficit of core, this region has 29 pairs of muscles that stabilize the spine, pelvis, and hip during movement. It is described as a box, in which the diaphragm delimits the upper part, the pelvic floor and the hip delimit the inferior part, the abdominal muscles in the anterior part and the paravertebral and gluteal muscles in the posterior part [20]. In the literature, the strength of the proximal core of the hip is necessary to control the distal segments to prevent injuries. Thus, the strength deficit of the core muscles plays a key role in the control of the knee, leg, and foot in the frontal and transverse planes [21]. Such impairments are present in this study, in which stress fracture was present in 100% of those affected by lateral core strength deficit and 33% in those with frontal core strength deficit. Also, 73% of those affected in the lateral core had shin splints, 67% had posterior tibial injuries and 50% had injuries to the peroneal tendons and ankle sprains. Tibial stress syndrome was present in 60% of those affected by frontal core strength deficit. Still in this group, 33% had posterior tibial injuries.

Varus knee is correlated with injuries such as patellofemoral stress syndrome, iliotibial band syndrome, and stress fractures [22]. In comparison with the present study, the only correlation present was plantar fasciitis, with 8% of those affected, and shin splints, with 15% of involvement. Dynamic knees, however, are related in the literature with patellofemoral stress syndrome, medial tibial stress syndrome [23]. In the present study, there is a greater correspondence to injuries than the varus knee. All patients (100%) had injuries to the peroneal tendons, 87% had shin splints, 83% had plantar fasciitis, 67% had posterior tibial injuries, 58% had Achilles tendinopathy, 60% had tibial stress syndrome, and 33% had stress fractures. The evaluated runners who did not present valgus or varus knees are considered with neutral alignment.

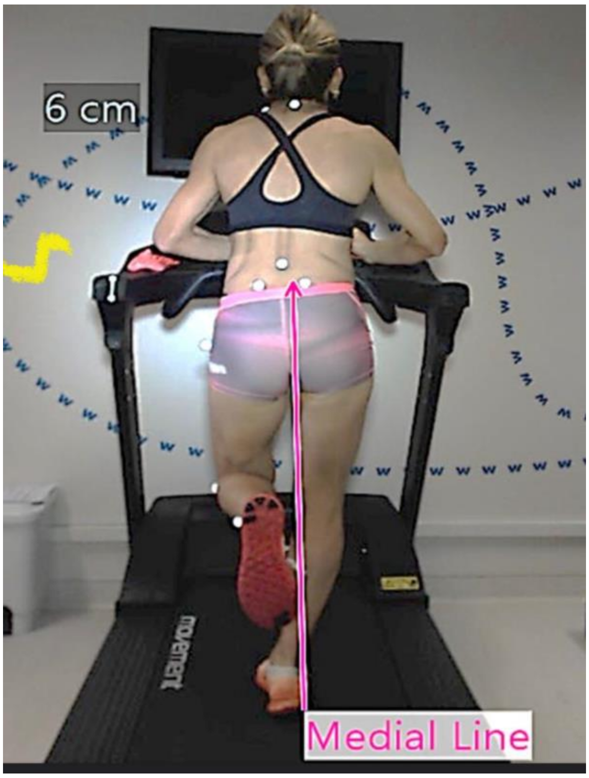
The Cross Over Gait pattern occurs in running when one foot or multiple feet cross the midline of the body, as a result the distance between the right and left step is almost negligible (Figure 3). Narrow Step Width is related to high mechanical stresses on the tibia and tibial stress fractures [24, 25]. In our analysis, the Cross Over pattern was present in 2 of the 3 cases of patients diagnosed with Tibial Tendonitis and was not present in the case of tibial stress fracture. Furthermore, it is worth mentioning the presence of the pattern in 11 out of the 15 cases of shin splints described.

The toe-out pattern is characterized by external rotation of the foot at 30 degrees from the sagittal line [26]. It is known that the toe-out pattern is more prevalent in people who have knee joint deviation, whether in varus or valgus [26]. This is also related to the presence of greater hip abduction and adduction, and to an increased chance of injury to the anterior cruciate ligament of the knee, compared to neutral or toe-in foot movement (internal rotation of the foot at 30°). In the present study, 33% patients with posterior tibial tendonitis had the toe-out pattern, as well as 17% of those with plantar fasciitis.

The center of mass vertical oscillation is defined as the vertical displacement of the trunk at each step, measured in centimeters. A smaller amplitude of the stride associated with a greater number of strides generates a decrease in the contact of the feet on the ground. In this way, there is a lower vertical oscillation and less energy savings. Increased vertical oscillation is associated with tibial stress fracture, plantar fasciitis, and patellofemoral pain [27]. In our study, center of mass vertical oscillation was present in 12 out of 15 (80%) of those affected by shin splints, in 3 out of 4 (75%) with injuries to the peroneal tendons and ankle sprains, in 8 out of 12 (67%) with plantar fasciitis, in 2 out of 3 (67%) with posterior tibial tendonitis, in 8 out of 12 (67%) with calcaneal tendinopathy, in 3 out of 5 (60%) with tibial stress syndrome and in 1 of 3 (33%) among those who had stress fractures in the lower limbs.

This study has some limitations. The small sample of patients does not allow the best biomechanical correlations of running with foot and ankle pathologies, and the scarce literature makes it difficult to analyze and correlate the measurements of this study with those previously published. As an alternative for better evidence, we propose a larger sample, as well as a greater availability of new studies that correlate with the present topic, for a more precise evaluation.

Figure 2: Patient presenting Cross Over Gait pattern during running, indicated by the stride on the midline.



5. Conclusions

In our study, the biomechanical analysis showed that the most common findings in the 56 patients evaluated were valgus knees, with 43 cases (76.78%), followed by pelvic drop and center of mass vertical oscillation, with 40 cases each (71.42%) and hamstring retraction, with 37 cases (66.07%). Among the least prevalent, varus knees and supinated foot stand out, with two cases each (3.57%) and medial or lateral heel whip, with three cases (5.35%).

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Conflicts of Interest: None.

Supplementary Materials: None.

References

1. Global Recommendations on Physical Activity for Health. WHO Guidelines Approved by the Guidelines Review Committee. Geneva: WHO Press, World Health Organization; 2010.
2. Taunton JE, Ryan MB, Clement DB, McKenzie DC, Lloyd-Smith DR, Zumbo BD. A retrospective case-control analysis of 2002 running injuries. Br J Sports Med. 2002 Apr;36(2):95-101. doi: 10.1136/bjsm.36.2.95.
3. Noehren B, Pohl MB, Sanchez Z, Cunningham T, Lattermann C. Proximal and distal kinematics in female runners with patellofemoral pain. Clin Biomech (Bristol, Avon). 2012 May;27(4):366-71. doi: 10.1016/j.clinbiomech.2011.10.005.
4. Noehren B, Schmitz A, Hempel R, Westlake C, Black W. Assessment of strength, flexibility, and running mechanics in men with iliotibial band syndrome. J Orthop Sports Phys Ther. 2014 Mar;44(3):217-22. doi: 10.2519/jospt.2014.4991.
5. Milner CE, Hamill J, Davis I. Are knee mechanics during early stance related to tibial stress fracture in runners? Clin Biomech 2007;22(6):697–703. doi: 10.1016/j.clinbiomech.2007.03.003.

6. Edwards WB, Taylor D, Rudolphi TJ, Gillette JC, Derrick TR. Effects of stride length and running mileage on a probabilistic stress fracture model. Med Sci Sports Exerc. 2009 Dec;41(12):2177-84. doi: 10.1249/MSS.0b013e3181a984c4.
7. Souza RB, Hatamiya N, Martin C, Aramaki A, Martinelli B, Wong J, Luke A. Medial and Lateral Heel Whips: Prevalence and Characteristics in Recreational Runners. PM&R. 2015;7(8):823–30. doi:10.1016/j.pmrj.2015.02.016.
8. Kilgore JE 3rd, Vincent KR, Vincent HK. Correcting Foot Crossover While Running. Curr Sports Med Rep. 2020 Jan;19(1):4-5. doi:10.1249/JSR.0000000000000670.
9. Noehren B, Davis I, Hamill J. ASB clinical biomechanics award winner 2006 prospective study of the biomechanical factors associated with iliotibial band syndrome. Clin Biomech (Bristol, Avon). 2007 Nov;22(9):951-6. doi: 10.1016/j.clinbiomech.2007.07.001.
10. Souza RB, Hatamiya N, Martin C, Aramaki A, Martinelli B, Wong J, Luke A. Medial and Lateral Heel Whips: Prevalence and Characteristics in Recreational Runners. PM R. 2015 Aug;7(8):823-830. doi: 10.1016/j.pmrj.2015.02.016.
11. Willson JD, Davis IS. Lower extremity mechanics of females with and without patellofemoral pain across activities with progressively greater task demands. Clin Biomech (Bristol, Avon). 2008 Feb;23(2):203-11. doi: 10.1016/j.clinbiomech.2007.08.025.
12. Powers CM. The Influence of Altered Lower-Extremity Kinematics on Patellofemoral Joint Dysfunction: A Theoretical Perspective Commentary. J Orthop Sports Phys Ther. 2003 Nov;33(11):639-46. doi:10.2519/jospt.2003.33.11.639.
13. Buchbinder MR, Napora NJ, Biggs EW. The relationship of abnormal pronation to chondromalacia of the patella in distance runners. J Am Podiatry Assoc. 1979 Feb;69(2):159-62. doi: 10.7547/87507315-69-2-159.
14. Tiberio D. The effect of excessive subtalar joint pronation on patellofemoral mechanics: a theoretical model. J Orthop Sports Phys Ther. 1987;9(4):160-5. doi:10.2519/jospt.1987.9.4.160.
15. Milner CE, Hamill J, Davis IS. Distinct hip and rearfoot kinematics in female runners with a history of tibial stress fracture. J Orthop Sports Phys Ther. 2010 Feb;40(2):59-66. doi: 10.2519/jospt.2010.3024.
16. Silbernagel KG, Willy R, Davis I. Preinjury and postinjury running analysis along with measurements of strength and tendon length in a patient with a surgically repaired Achilles tendon rupture. J Orthop Sports Phys Ther. 2012 Jun;42(6):521-9. doi: 10.2519/jospt.2012.3913.
17. Souza RB. An Evidence-Based Videotaped Running Biomechanics Analysis. Phys Med Rehabil Clin N Am. 2016 Feb;27(1):217-36. doi: 10.1016/j.pmr.2015.08.006.
18. Souza RB, Hatamiya N, Martin C, Aramaki A, Martinelli B, Wong J, Luke A. Medial and Lateral Heel Whips: Prevalence and Characteristics in Recreational Runners. PM R. 2015 Aug;7(8):823-830. doi: 10.1016/j.pmrj.2015.02.016.
19. Aranda Y, Munuera PV. Plantar fasciitis and its relationship with hallux limitus. J Am Podiatr Med Assoc. 2014 May;104(3):263-8. doi: 10.7547/0003-0538-104.3.263.
20. Akuthota V, Ferreiro A, Moore T, Fredericson M. Core stability exercise principles. Curr Sports Med Rep. 2008 Feb;7(1):39-44. doi: 10.1097/01.CSMR.0000308663.13278.69.
21. Niemuth PE, Johnson RJ, Myers MJ, Thieman TJ. Hip muscle weakness and overuse injuries in recreational runners. Clin J Sport Med. 2005 Jan;15(1):14-21. doi: 10.1097/00042752-200501000-00004.
22. Krivickas, LS. Anatomical Factors Associated with Overuse Sports Injuries. Sports Med. 1997 Aug;24(2):132-46. doi: 10.2165/00007256-199724020-00005.
23. Alfayez SM, Ahmed ML, Alomar AZ. A review article of medial tibial stress syndrome. J Musculoskelet Surg Res 2017;1:2-5.
24. Meardon SA, Derrick TR. Effect of step with manipulation on tibial stress during running. J Biomech. 2014 Aug 22;47(11):2738-44. doi: 10.1016/j.jbiomech.2014.04.047.
25. Nunns M, House C, Rice H, Mostazir M, Davey T, Stiles V, Fallowfield J, Allsopp A, Dixon S. Four biomechanical and anthropometric measures predict tibial stress fracture: a prospective study of 1065 Royal Marines. Br J Sports Med. 2016 Oct;50(19):1206-10.
26. Lee J, Pathak P, Panday SB, Moon J. Effect of Foot-Planting Strategy on Anterior Cruciate Ligament Loading in Women During a Direction Diversion Maneuver: A Musculoskeletal Modeling Approach. Orthop J Sports Med. 2020 Nov 19;8(11):2325967120963180.
27. Adams D, Pozzi F, Willy RW, Carrol A, Zeni J. Altering cadence or vertical oscillation during running: effects on running related injury factors. Int J Sports Phys Ther. 2018 Aug;13(4):633-642.