DOI: 10.22122/jrrs.v16i0.3579 Published by Vesnu Publications

Comparison of Maximum Angles of Knee Varus and Flexion in the Stance Phase of Walking on a Treadmill with Different Inclinations between Female Athletes with Genu Valgum and Healthy Knees

Katayoon Gilani[1], Fariborz Mohammadipour[2], Mohammadreza Amirseyfaddini[2]

Original Article

Abstract

Introduction: The use of treadmills and sports equipment is on the rise due to long stay at home because of the progression of Coronavirus Disease (COVID-19), and hence, tendency of individuals to exercise at home. Common movement patterns in non-contact anterior cruciate ligament (ACL) injuries include decreased knee flexion accompanied by increased knee valgus angles. Therefore, the aim of this study is to investigate the maximum angles of knee varus and flexion when walking on positive, negative, and zero treadmill inclinations.

Materials and Methods: 29 subjects within the age range of 18-28 years were selected and divided into two groups of healthy (weight: 58.95 ± 8.58, height: 163.14 ± 3.95, intermalleolar distance: 0.46 ± 0.40) and genu valgum (weight: 61.60 ± 5.56, height: 161.80 ± 5.50, intermalleolar distance: 6.95 ± 2.51). The parameters of maximum angles of knee varus and flexion when walking on -10, zero, +10% treadmill inclinations were calculated using three-dimensional motion analysis system. The data were processed in Cortex and MATLAB softwares and analyzed using mixed repeated measure at the significant level of $P < 0.050$.

Results: The results of this study showed that the highest values of maximum angles of knee varus and flexion were observed at -10% inclination. In addition, the maximum varus angle did not differ significantly between the positive and zero inclinations, but the maximum flexion angle showed a significant difference between these two inclinations.

Conclusion: Since walking on negative inclinations inclines the knee angle in the frontal plane toward the varus and increases the flexion angle and decreases the load exerted on the ACL, this type of walking can be more effective in rehabilitating people with genu valgum.

Keywords: Gait; Inclined slope; Declined slope; Knee range of motion

Citation: Gilani K, Mohammadipour F, Amirseyfaddini M. **Comparison of Maximum Angles of Knee Varus and Flexion in the Stance Phase of Walking on a Treadmill with Different Inclinations between Female Athletes with Genu Valgum and Healthy Knees.** J Res Rehabil Sci 2020; 16: 142-50.

Received: 04.07.2020 Accepted: 16.08.2020 Published: 05.08.2020

Introduction

Moving on inclined surfaces is a challenging task in everyday life, especially when walking. It is also a popular leisure activity in mountainous areas. The positive effects of walking have been proven (1), but this exercise can also cause pain and damage to the musculoskeletal system (2). In a study, pain in the knee joint while walking downhill was reported (3).

Today, due to the epidemic of Coronavirus Disease (COVID-19) and the lack of sports facilities and turning to home sports, the use of sports equipment such as treadmills is increasing and newer types of treadmills have the capability of choosing the surface slope for sports activities. Biomechanical research on walking has shown that most people emphasize walking on a horizontal surface (4-7). Nevertheless, the study of the biomechanics of walking on sloping surfaces can lead to a better understanding of slips and falls, construction of rehabilitation equipment, and the design of artificial limbs (8).

1- MSc Student, Department of Sport Biomechanics, School of Physical Education and Sport Science, Shahid Bahonar University of Kerman, Kerman, Iran
2- Associate Professor, Department of Sport Biomechanics School of Physical Education and Sport Science, Shahid Bahonar University of Kerman, Kerman, Iran
Corresponding Author: Fariborz Mohammadipour, Email: mp_fariborz@uk.ac.ir

In gait, the stage at which the foot touches the ground to the stage when it leaves it is called the stance phase. This stage is also called the weight bearing stage; because in this case, the weight of the body is carried on the leg. Since the knee bears more load at this stage (9,10), this stage has been investigated in the present study.

Genu valgum is a type of deformity of the knee in the frontal plane that, in case of presence, if the knees are in contact with each other in the weight-bearing position, the ankle joints will be spaced apart. This deformity is of a relatively high prevalence in Iran, especially among women (11-13).

The knee varus and valgus angles unbalance the load distribution on the joint surface, and the valgus level compared to the normal level can cause osteoarthritis (14). In genu valgum, the stress forces exerted on the outer part of the knee joint increase (15). Genu valgus abnormalities can also increase the risk of external osteoarthritis (16,17). The position of the lower limb, which directly affects the load on the anterior cruciate ligament (ACL), is believed to play an important role in increasing the risk of ACL injury (18). In fact, common movement patterns in non-contact ACL injuries include a decrease in knee flexion, pelvic flexion, and trunk flexion with an increase in knee valgus and tibial rotation (19-21). For this purpose, in the present study, changes in flexion and varus angles were investigated in order to better understand walking on positive and negative slopes. In this regard, the results can be used to apply or not to apply a slope in walking exercises to rehabilitate individuals, especially ones with genu valgum.

Materials and Methods

This was a quasi-experimental, causal, and applied study. To perform the study, with the cooperation of the Sports Medicine Board and a number of clubs in Kerman, Iran, first 15 athletes with grade 3 and higher genu valgum were selected. Then, given the same demographic characteristics and self-selected walking speed, other 15 people were placed in the control group. To determine the required sample size, G*Power software version 3.1.7 was used. To obtain 75% statistical power with a significance level of 0.05 and an effect size of 0.25, 30 subjects were required. One of the subjects withdrew from the study. The statistical population of the study consisted of all women athletes in the field of fitness and Total-body resistance exercise (TRX) in clubs in Kerman. The purposive and convenience method was adopted for sampling. The study inclusion criteria included age 18 to 28 years, regular exercise for at least three sessions weekly, female gender, no history of fracture or lower limb surgery, and in the genu valgum group, the intermalleolar distance between 5 and 7.5 cm (grade 3 genu valgum) or more than 7.5 cm (grade 4 genu valgum) (22). In addition, a history of neuromuscular-musculoskeletal disorders, a history of surgery or lower limb injury over the past six months, a history of ankle sprains, and visible lower limb malalignments including genu varum, Genu Recurvatum, flat feet, and pes cavus were also considered as the exclusion criteria. Lower limb injury was defined as any injury that resulted in an absence of more than one day of physical activity or a visit to the physician (23).

At the beginning of data collection, on the day of interviewing the subjects, their lower limb health assessment information was assessed using a questionnaire. Then the desired samples were selected and invited to test. At the beginning of the test, all subjects read and signed the consent form. Then, they got acquainted with the test process. In order to ensure that the work process was principled, the study was ethically reviewed by the ethics committee of Shahid Bahonar University of Kerman and approved with the ethics code IR.UK.VETMED.REC.1398.016. Demographic information of the subjects was collected. To determine the grade of the genu valgum in individuals, a caliper (Vernier, Mitutoyo, Japan) was used with an accuracy of 0.01 m to measure the intermalleolar distance. The subject stood without shoes and socks, with her knees and lower thighs visible (quite easily), in front of the examiner on a flat surface upright with her legs parallel to each other, without suffering abnormal contraction and tension in the thigh muscles. Her inner femoral condyles and medial malleoluses were at the closest distance to each other in a normal position, and her hips and knees were in full extension. The intermalleolar distance was measured twice and their mean was calculated (24). To determine the dominant foot, the method of shooting a soccer ball for maximum distance was used. The subjects were asked to walk barefoot three times on a 10-meter path at their desired speed and the walking time was recorded by the tester with a stopwatch. After completing three runs, the average speed obtained was considered to adjust the speed of the treadmill for each person (25,26). In the next step, marking was performed while the subject was wearing the least clothing on her lower limbs (sports shorts). The marking sites included the anterior and middle surface of the leg in the distal part of the tibia, the tibial tuberosity, the midline of the line connecting the anterior superior iliac spine to the patella, the heel bone and big toe of the right foot (the dominant foot of all subjects), and the heel bone and big toe of the left foot (25,27,28).

In order to record 3D motion information, the 3D motion analysis system (Rapture-H Digital Real Time System, Motion Analysis, USA) was used with six infrared cameras, which were placed around the designated space so that the information of each marker was recorded by at least two cameras at each moment of movement. This system is capable of 3D video recording up to 900 frames per second. In the present study, the frequency of the cameras was considered to be 120 Hz.

The position of the subjects' markers was randomly filmed for 5 seconds. Moreover, each subject performed three tests of walking on slopes of +10%, 0, and -10% on the treadmill at her self-selected speed. Since the treadmill lacked a negative slope, several brick blocks were used to apply the negative slope. To perform the tests, a treadmill (J880, Tunturi, Netherlands) with the ability to adjust different speeds and positive slopes was used. The treadmill surfaces were covered with newspaper to prevent light reflection. For each test, the subjects were given 5 minutes to adjust to walking on the treadmill (29-31). Between the tests, a 1-minute break was considered for the subject in order to reduce the intervention of the fatigue factor. After the preparation of the subject and the diagnosis of the examiner, the recording was conducted for 20 seconds. The testing of the individuals was carried out in a random manner (29). The data recorded were analyzed in Cortex software version 2.5. A 6 Hz Butterworth low-pass filter (LPF) was used to eliminate the noise induced by the movement of the markers.

In order to reduce the data, a video recording of five consecutive steps selected from the middle part was used.

In static test analysis, first the markers were defined and then the velocity and acceleration diagrams were examined and the frames with the least changes were selected and after filtering the data, the information was extracted. Then, the desired indices including the heel strike and toe-off moments were obtained given the speed-based treadmill algorithm (32). To obtain the knee angles in the frontal plane using the joint coordinate system method and through Matlab software version R2018a, the desired program code was written, so that using the spatial data of the markers installed on the thigh, tibial tuberosity, and tibia, the knee angle on the frontal plate was calculated. After determining the stance phase and obtaining the maximum flexion and varus angles in this phase, the angular changes relative to the static phase of each subject were calculated.

The Shapiro-Wilk test was employed to examine the normal distribution of the variables and mixed model for repeated measures (MMRM) test to compare the data of the two groups. To evaluate the homogeneity of variances and to determine the effect size (η^2), the Levene's test and Partial Eta squared test (low effect size = 0.01, medium effect size = 0.06, and high effect size = 0.14) were utilized, respectively (33,34). Besides, the Box's M test was exploited to determine the equality (homogeneity) of the covariance matrix, and the results of Greenhouse-Geisser test were used due to the violation of the sphericity assumption (Mauchly test). Furthermore, the Bonferroni post hoc test was used to compare between different slopes. Finally, the data were analyzed in SPSS software (version 23, IBM Corporation, Armonk, NY, USA), given $P < 0.05$ considered as the significant level.

Results

The anthropometric characteristics and self-selected gait speed of the participants in the present study are shown in table 1. The Shapiro-Wilk test was used to check the normality of the data and given the normal distribution of the data, independent t-test was used to evaluate the differences between the healthy and genu valgum groups.

Table 1. Anthropometric characteristics and self-selected gait speed of the genu valgum group (n = 15) and control group (n = 14)

Index	Group	Mean ± SD	P
Age (year)	Control	23.50 ± 2.90	0.794
	Genu valgum	23.53 ±2.44	
Height (cm)	Control	163.14 ±3.95	0.460
	Genu valgum	161.80 ±5.50	
Mass (kg)	Control	58.95 ± 8.58	0.339
	Genu valgum	61.60 ± 5.56	
Intermalleolar distance in standing position (cm)	Control	0.46 ± 0.40	0.001*
	Genu valgum	6.95 ±2.51	
Self-selected walking speed (km/hour)	Control	3.32 ± 0.58	0.241
	Genu valgum	3.10 ± 0.40	

SD: Standard deviation
*Presence of a significant difference

The MMRM test results showed that there was no significant difference between the two genu valgum and control groups in relation to the varus angle ($F = 0.545$, $P = 0.467$). Given the Greenhouse-Geisser test results, the difference between the interaction of slopes and groups was not significant ($F = 0.844$, $P = 0.461$), but the comparison between different slopes was significant ($\eta^2 = 0.286$, $P = 0.001$, $F = 10.804$). On the negative slope, the greatest change in knee angle was observed in the frontal plane towards the varus. The results of data scatter (Figure 1) along with the significance level in relation to the maximum varus angle change are shown in table 2.

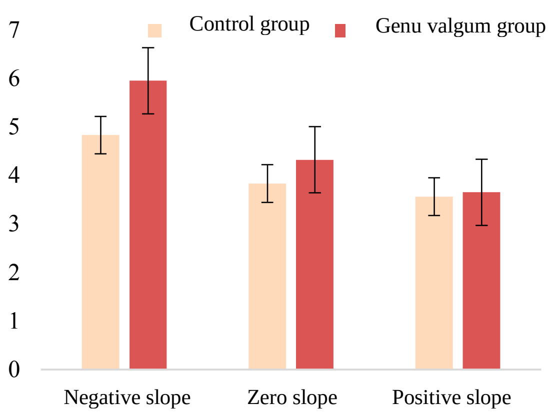

Figure 1. Comparison of the mean maximum varus angles in different slopes in subjects with genu valgum and healthy subjects

The results regarding the maximum change of flexion angle indicated that there was a significant difference between the two groups ($\eta^2 = 0.194$, $P = 0.017$, $F = 6.482$). On the basis of the results of the Greenhouse-Geisser test, the difference between the interaction of slopes and groups ($F = 0.260$, $P = 0.746$) was not significant, but the comparison between different slopes ($\eta^2 = 0.566$, $P = 0.001$, $F = 35.209$) was significant. Similar to the varus angle, in the negative slope, the greatest amount of change in the knee flexion angle was observed. The data scatter results (Figure 2) along with the level of significance in relation to the comparison between different slopes are presented in table 3.

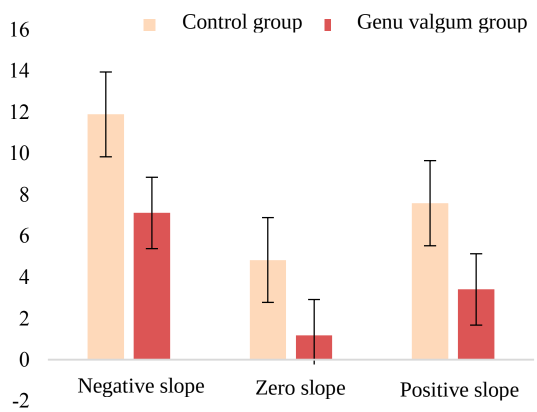

Figure 2. Comparison of the mean of maximum flexion angles in different slopes in the genu valgum group and control group

Discussion

The aim of this study was to investigate the effect of positive and negative slope of 10% of the treadmill on the maximum change of varus and flexion angles during the stance phase of walking. The variables of varus angle and flexion angle were selected in terms of relation with the genu valgum and ACL rehabilitation group.

The results obtained for the varus angle were consistent with the findings of studies by Haggerty et al. (35), Stevens et al. (36), and Naderi et al. (37). In the study of Haggerty et al., with increasing the slope in the positive direction, an increase in the maximum valgus angle was observed in the stance phase, but the differences from the zero slope were not significant (35). In the present study, the reduction of the maximum varus angle in the positive slope was observed, but the differences were not significant.

Table 2. Results of scattering of maximum varus angles in the genu valgum group (n = 15) and control group (n = 14)

Index	Group	Mean ± SD	Comparison between slopes	P
Maximum varus angle change while walking on the negative slope	Control	4.83 ± 3.28	Negative slope, zero slope	0.007*
	Genu valgum	5.95 ± 2.77	Negative slope, positive slope	0.002*
Maximum varus angle change while walking on the zero slope	Control	3.83 ± 2.17	Zero slope, negative slope	0.007*
	Genu valgum	4.32 ± 1.59	Zero slope, positive slope	0.470
Maximum varus angle change while walking on positive slope	Control	3.56 ± 2.51	Positive slope, negative slope	0.002*
	Genu valgum	3.65 ± 1.72	Positive slope, zero slope	0.470

SD: Standard deviation
*Presence of a significant difference

Table 3. Results of scatter of maximum flexion angles in genu valgum (n = 15) and control groups (n = 14)

Index	Group	Mean ± SD	Comparison between slopes	P
Maximum flexion angle change while walking on negative slope	Control	11.90 ± 4.72	Negative slope, zero slope	0.001*
	Genu valgum	7.12 ± 5.91	Negative slope, positive slope	0.001*
Maximum flexion angle change while walking on zero slope	Control	4.83 ± 4.23	Zero slope, negative slope	0.001*
	Genu valgum	1.18 ± 4.23	Zero slope, positive slope	0.007*
Maximum flexion angle change while walking on positive slope	Control	7.59 ± 5.68	Positive slope, negative slope	0.001*
	Genu valgum	3.41 ± 5.31	Positive slope, zero slope	0.007*

SD: Standard deviation

*Presence of a significant difference

In line with the results of Stevens et al., the peak and mean knee torques in the varus direction during stance were higher in the subjects with genu valgum compared to the healthy individuals (36), which was similar to the results of the present study. Accordingly, the change in the maximum varus angle was higher in individuals with genu valgum than in the healthy group, but the general differences between the two groups were not significant, which could be due to differences in the nature of the variables examined in the two studies. The varus angle was investigated in the present study, however in Stevens et al., the knee torques causing the angle change in the frontal plane were investigated (36).

In their study, Naderi et al. addressed the varus angle on the frontal plane in individuals with genu varum, concluding that decrease in varus angle was associated with increased inclination (37), which was in agreement with the findings of the present study. Additionally, the results of another study conducted by Naderi et al. on healthy individuals revealed that with increasing the slope in a positive direction in healthy individuals, the varus angle decreases and regarding the negative slope, in the slope of -7.5% compared to the zero slope, the varus angle increased (38), which was consistent with the findings of the present study.

According to Yang et al., the knee torques on the frontal plane decreased in positive slopes relative to the zero slope during the stance phase of walking, but the knee torques in the -12 and -20 degree slopes were not much different from those in the zero slope and increased in -6 degree slope (39), which was in line with the findings of the current study. The results of the study accomplished by Lange et al. suggested that the range of motion (ROM) of the knee joint decreased with increasing slope (40), which was consistent with the results of the present study.

Given the results of Shultz et al., the maximum angular displacement in relation to external rotation while walking was higher in obese people with genu valgum than in healthy individuals, which contradicted the findings of the present study. The results of Espandar et al.'s study on the combination of knee alignment in the frontal and horizontal planes showed that obese children maintain a true position of genu valgum during functional movements, and this may be a reason for greater external rotation of the knee in people with genu valgum (42).

The results of Han et al.'s study suggested that the knee varus angle increased with increasing slope at the moment of heel strike and mid-stance and decreased at the moment of toe-off (43), which did not agree with the results of the present study. In the present study, the maximum varus occurred at the end of the stance phase, but in the study of Han et al., the knee angle shifted toward the valgus at the end of the stance phase (43). One of the reasons for this difference is the unequal speed of walking on different slopes and also the lack of use of treadmills by Han et al. (43). In the study by Han et al., the subjects walked on an inclined plane that was three meters long (43) and according to Vogt and Banzer, the usual response to the slope increase was to walk more slowly and take shorter steps (44), but to minimize the effects of speed in the present study, the walking speed of each person was considered the same in all slopes. Other reasons for this discrepancy include the use of different measurement tools as well as the non-normalization of data by Han et al. (43). In order to minimize the marking error in the present study, the subjects were first filmed in a standing position and then the angular changes made while walking were compared with the standing position. Other reasons for this difference may be the different statistical sample of the two studies. In the study of Han et al., which was performed only on healthy individuals, men were more than women (43), but in the present study, people with genu valgum were also considered. Differences between the sexes such as skeletal orientation, muscle strength, and body size can affect their performance. In general, women take shorter and faster steps than men. Chung and Wang stated that when walking, there was a significant difference in the maximum ground reaction force (GRF) between the two sexes; so that it was reported that women had a higher maximum GRF compared to men in the phases of heel strike with the ground and toe-off (45). The results of previous investigations have shown that a slight change in the knee angle in the frontal plane causes a large change in knee torque (46). Shultz et al. concluded that a 2 degree change in the knee valgus increased the valgus torque by 40 N.m (42). Therefore, given the findings of the present study on increasing the varus angle while walking on a -10% slope, this method can be considered as a way of rehabilitation, especially for people with genu valgum.

The results of the present study regarding the flexion angle were similar to the findings of Astephen et al. (47), Fattahi et al. (48), and Lay et al. (49). The results of Astephen et al. indicated that the peak knee flexion angle during walking in people with severe osteoarthritis is significantly lower than that in asymptomatic people (47). In the present study, it was also observed that the knee flexion angle is lower in patients with genu valgum than in healthy individuals. In the study of Lay et al., an increase in knee flexion angle was observed in positive and negative slopes (49). This may be due to the fact that while walking on the positive slope, the knee flexion and extension angles increase respectively during the heel strike and during the mid-stance due to the increase in height and body displacement upwards. Moreover, when walking on a negative slope, a greater knee flexion angle in the stance phase is necessary to move the body downward.

The results of the study by Rodenbusch et al. showed that at a positive slope of 10%, the maximum angle of flexion of the knee was less than that on the zero slope (27), which contradicted the findings of the present study. The reason for this discrepancy may be due to the different subjects of the two studies. The target population of the study by Rodenbusch et al. (27) was children with Down syndrome. In patients with diseases like hemiplegia, Down syndrome, or spinal cord injuries whose nervous system is damaged, changing the walking slope changes the gait parameters of these patients (25). According to Thelen and Ulrich’s study, walking on different slopes leads to new forms of behavior in cooperation between different components and the ground for tasks. When disorders that facilitate these interactions are imposed on a person, they make motor skills more functional (50), but in the case of young people with genu valgum, given their healthy nervous system and lack of destruction or loss of articular cartilage, walking on inclined surfaces has a similar pattern to that in healthy people.

As the results of previous studies, increasing the knee flexion angle during exercise reduces the forces on the ACL. Anterior shear force is the main determinant of the amount of load applied to the ACL (51). As flexion in the knee increases, the angle between the patellar tendon and the tibia increases, and the force resulting from the contraction of the quadriceps in the proximal tibia produces less anterior shear force (52). Additionally, the increase in knee flexion is associated with a decrease in the posterior GRF, and since the posterior GRF is directly related to the amount of anterior shear force in the proximal tibia (53), it can be said that increasing knee flexion will reduce the ACL force. Therefore, given the results obtained on the increase in the flexion angle while walking on a negative slope, it seems that a new look should be taken on exercises on the negative slopes.

Limitations

The main limitation of this study was the different experience and history of the subjects of walking on a treadmill. Another limitation of this study was the possibility of effect of the markers on the performance of the subjects. Lack of control over anxiety and motivation and mood of the subjects was another limitation of the study.

Recommendations

Given the results, since walking on a negative slope leads to an increase in the knee varus angle, it is therefore suggested that this method of walking be included as a suitable physical activity in training and rehabilitation programs of individuals with genu valgum.

Conclusion

Dynamic knee valgus (DKV) increases the risk of multiple lower limb injuries. In younger people, both ACL injury and Patellofemoral pain syndrome (PFPS) are often associated with DKV (54,55). Increasing the varus angle causes the knee to be less in a dynamic valgus position, so it can play an important role in rehabilitating people with ACL and PFPS injury. Therefore, taking into account the results obtained in relation to the varus angle, since walking on a negative slope inclines the knee angle in the frontal plane towards varus and on the other hand, increases the flexion angle and decreases the load on ACL, this type of gait can be more effective in rehabilitating patients with genu valgum. These results can help coaches and physiotherapists design injury, prevention, and exercise programs.

Acknowledgments

The present study was extracted from an MSc thesis in sports biomechanics approved by Shahid Bahonar University of Kerman. The authors would like to appreciate Dr. Abdolhamid Daneshjoo, who contributed to pathology and statistics, and Mr. Sasan Naderi, who contributed to programming code in Matlab.

Authors' Contribution

Katayoon Gilani: Study design and ideation, attracting financial resources for the study, providing study equipment and samples, data collection, specialized statistical services, manuscript preparation, specialized evaluation of manuscript in terms of scientific concepts, approval of the final manuscript to be sent to the journal office, responsibility for maintaining the integrity of the study process from the beginning to publishing, and responding to referees' comments; Fariborz Mohammadipour: study support, executive, and scientific services, analysis and interpretation of results, manuscript preparation, specialized evaluation of manuscript in terms of scientific concepts, approval of the final manuscript to be sent to the journal office, responsibility for maintaining the integrity of the study process from the beginning to publishing, and responding to referees' comments; Mohammadreza Amirseyfaddini: study support, executive, and scientific services, providing study equipment and samples, analysis and interpretation of results, manuscript preparation, specialized evaluation of manuscript in terms of scientific concepts, approval of the final manuscript to be sent to the journal office, responsibility for maintaining the integrity of the study process from the beginning to publishing, and responding to referees' comments.

Funding

The present study was based on the secondary analysis of part of the information extracted from an MSc dissertation on Sports Biomechanics with ethics code IR.UK.VETMED.REC.1398.016 and Iranian Registry of Clinical Trials (IRCT) code IRCT20200721048165N1, which was prepared with the financial support of Shahid Bahonar University of Kerman. Shahid Bahonar University of Kerman did not comment on data collection, analysis, and reporting, manuscript preparation, and final approval of the article for publication.

Conflict of Interest

The authors have no conflict of interest.

References

1. Greie S, Humpeler E, Gunga HC, Koralewski E, Klingler A, Mittermayr M, et al. Improvement of metabolic syndrome markers through altitude specific hiking vacations. J Endocrinol Invest 2006; 29(6): 497-504.
2. Blake RL, Ferguson HJ. Walking and hiking injuries. A one year follow-up study. J Am Podiatr Med Assoc 1993; 83(9): 499-503.
3. Schwameder H. Biomechanische Belastungsanalysen beim Berggehen. Aachen, Germany: Meyer + Meyer Fachverlag; 2004.
4. Davis RB, Ounpuu S, Tyburski D, Gage JR. A gait analysis data collection and reduction technique. Hum Movement Sci 1991; 10(5): 575-87.
5. Kadaba MP, Ramakrishnan HK, Wootten ME. Measurement of lower extremity kinematics during level walking. J Orthop Res 1990; 8(3): 383-92.
6. Perry J, Slac T, Davids JR. Gait Analysis: Normal and pathological function. J Pediatr Orthop1992; 12(6): 815.
7. Winter DA. The biomechanics and motor control of human gait: Normal, elderly and pathological. Waterloo, ON, Canada: University of Waterloo Press; 1991.
8. McIntosh AS, Beatty KT, Dwan LN, Vickers DR. Gait dynamics on an inclined walkway. J Biomech 2006; 39(13): 2491-502.
9. Perry J, Burnfield J, Burnfield JM. Gait analysis: normal and pathological function. 2nd ed. Thorofare, NJ: Slack; 2010.
10. Whittle M. Gait analysis: An introduction. New York, NY: Butterworth-Heinemann; 2007.
11. Akhavirad SMB, Mahdi Barzi D, Jashan S, Radmanesh M. Prevalence of foot and knee deformities among high school female students in Tehran district no.5. Hakim Res J 2006; 9(2): 18-23. [In Persian].
12. Ghandi AR, Hadi HA, Behruzi AR, Holakooie AR. The prevalence of genu-varum in students aged 7-16 in Arak city. J Arak Uni Med Sci 2012; 15(4): 63-8. [In Persian].
13. Karimi-Mobarake M, Kashefipour A, Yousfnejad Z. The prevalence of genu varum and genu valgum in primary school children in Iran 2003-2004. J Med Sci 2005; 5(1): 52-54.
14. Brouwer GM, van Tol AW, Bergink AP, Belo JN, Bernsen RM, Reijman M, et al. Association between valgus and varus alignment and the development and progression of radiographic osteoarthritis of the knee. Arthritis Rheum 2007; 56(4): 1204-11.
15. Tetsworth K, Paley D. Malalignment and degenerative arthropathy. Orthop Clin North Am 1994; 25(3): 367-77.
16. Cerejo R, Dunlop DD, Cahue S, Channin D, Song J, Sharma L. The influence of alignment on risk of knee osteoarthritis progression according to baseline stage of disease. Arthritis Rheum 2002; 46(10): 2632-6.
17. Sharma L, Song J, Felson DT, Cahue S, Shamiyeh E, Dunlop DD. The role of knee alignment in disease progression and functional decline in knee osteoarthritis. JAMA 2001; 286(2): 188-95.

18. Boden BP, Torg JS, Knowles SB, Hewett TE. Video analysis of anterior cruciate ligament injury: Abnormalities in hip and ankle kinematics. Am J Sports Med 2009; 37(2): 252-9.
19. Ireland ML. Anterior cruciate ligament injury in female athletes: Epidemiology. J Athl Train 1999; 34(2): 150-4.
20. Krosshaug T, Nakamae A, Boden BP, Engebretsen L, Smith G, Slauterbeck JR, et al. Mechanisms of anterior cruciate ligament injury in basketball: Video analysis of 39 cases. Am J Sports Med 2007; 35(3): 359-67.
21. Olsen OE, Myklebust G, Engebretsen L, Bahr R. Injury mechanisms for anterior cruciate ligament injuries in team handball: A systematic video analysis. Am J Sports Med 2004; 32(4): 1002-12.
22. Morley AJ. Knock-knee in children. Br Med J 1957; 2(5051): 976-9.
23. Nguyen AD, Boling MC, Levine B, Shultz SJ. Relationships between lower extremity alignment and the quadriceps angle. Clin J Sport Med 2009; 19(3): 201-6.
24. Mokhtari G, Mahdavinejad R, Mokhtari Azar A, Ebadifara M. Determination of normal index of lower extremity alignment (Knee valgus and varus) in normal men and women. J Res Rehabil Sci 2013; 9(2): 243-52. [In Persian].
25. Moreno CC, Mendes LA, Lindquist AR. Effects of treadmill inclination on the gait of individuals with chronic hemiparesis. Arch Phys Med Rehabil 2011; 92(10): 1675-80.
26. Werner C, Lindquist AR, Bardeleben A, Hesse S. The influence of treadmill inclination on the gait of ambulatory hemiparetic subjects. Neurorehabil Neural Repair 2007; 21(1): 76-80.
27. Rodenbusch TL, Ribeiro TS, Simao CR, Britto HM, Tudella E, Lindquist AR. Effects of treadmill inclination on the gait of children with Down syndrome. Res Dev Disabil 2013; 34(7): 2185-90.
28. Munro A, Herrington L, Comfort P. Comparison of landing knee valgus angle between female basketball and football athletes: Possible implications for anterior cruciate ligament and patellofemoral joint injury rates. Phys Ther Sport 2012; 13(4): 259-64.
29. Alexander N, Schwameder H. Lower limb joint forces during walking on the level and slopes at different inclinations. Gait Posture 2016; 45: 137-42.
30. Alexander N, Schwameder H. Effect of sloped walking on lower limb muscle forces. Gait Posture 2016; 47: 62-7.
31. Varma RK, Duffell LD, Nathwani D, McGregor AH. Knee moments of anterior cruciate ligament reconstructed and control participants during normal and inclined walking. BMJ Open 2014; 4(6): e004753.
32. Zeni JA, Richards JG, Higginson JS. Two simple methods for determining gait events during treadmill and overground walking using kinematic data. Gait Posture 2008; 27(4): 710-4.
33. Pallant J. SPSS Survival Manual: A Step-by-step Guide to Data Analysis Using SPSS for Windows (Version 10). London, UK: Open University Press; 2001.
34. Ma Y, Liang Y, Kang X, Shao M, Siemelink L, Zhang Y. Gait Characteristics of children with spastic cerebral palsy during inclined treadmill walking under a virtual reality environment. Appl Bionics Biomech 2019; 2019: 8049156.
35. Haggerty M, Dickin DC, Popp J, Wang H. The influence of incline walking on joint mechanics. Gait Posture 2014; 39(4): 1017-21.
36. Stevens PM, MacWilliams B, Mohr RA. Gait analysis of stapling for genu valgum. J Pediatr Orthop 2004; 24(1): 70-4.
37. Naderi S, Mohammadipour F, Amir Seyfaddini MR. The effects of different walking inclinations on knee angle in the frontal plane of patients with varus malalignment. Physical Treatments 2014; 4(3): 139-44. [In Persian].
38. Naderi S, Mohammadipour F, Amir Seyfaddini MR. Kinematics of lower extremity during forward and backward walking on different gradients. Physical Treatment 2017; 7(2): 71-8. [In Persian].
39. Yang Z, Qu F, Liu H, Jiang L, Cui C, Rietdyk S. The relative contributions of sagittal, frontal, and transverse joint works to self-paced incline and decline slope walking. Journal of Biomechanics 2019; 92: 35-44.
40. Lange GW, Hintermeister RA, Schlegel T, Dillman CJ, Steadman JR. Electromyographic and kinematic analysis of graded treadmill walking and the implications for knee rehabilitation. J Orthop Sports Phys Ther 1996; 23(5): 294-301.
41. Shultz SP, D'Hondt E, Fink PW, Lenoir M, Hills AP. The effects of pediatric obesity on dynamic joint malalignment during gait. Clin Biomech (Bristol, Avon) 2014; 29(7): 835-8.
42. Espandar R, Mortazavi SM, Baghdadi T. Angular deformities of the lower limb in children. Asian J Sports Med 2010; 1(1): 46-53.
43. Han J, Kwon YH, Park Jw, Koo H, Nam K. Three-Dimensional kinematic analysis during upslope walking with different inclinations by healthy adults. J Phys Ther Sci 2009; 21(4): 385-91.
44. Vogt L, Banzer W. Measurement of lumbar spine kinematics in incline treadmill walking. Gait Posture 1999; 9(1): 18-23.
45. Chung MJ, Wang MJ. The change of gait parameters during walking at different percentage of preferred walking speed for healthy adults aged 20-60 years. Gait Posture 2010; 31(1): 131-5.
46. McLean SG, Huang X, van den Bogert AJ. Association between lower extremity posture at contact and peak knee valgus moment during sidestepping: Implications for ACL injury. Clin Biomech (Bristol, Avon) 2005; 20(8): 863-70.
47. Astephen JL, Deluzio KJ, Caldwell GE, Dunbar MJ. Biomechanical changes at the hip, knee, and ankle joints during gait are associated with knee osteoarthritis severity. J Orthop Res 2008; 26(3): 332-41.
48. Fatahi F, Ghasemi GA, Karimi MT, Beyranvand R. Can eight weeks of stabilization exercise change the amount of knee flexion and anterior shear force? J Clin Anal Med 2018; 9(3): 203-8.

49. Lay AN, Hass CJ, Gregor RJ. The effects of sloped surfaces on locomotion: a kinematic and kinetic analysis. J Biomech 2006; 39(9): 1621-8.
50. Thelen E, Ulrich BD. Hidden skills: A dynamic systems analysis of treadmill stepping during the first year. Monogr Soc Res Child Dev 1991; 56(1): 1-98.
51. Markolf KL, Burchfield DM, Shapiro MM, Shepard MF, Finerman GA, Slauterbeck JL. Combined knee loading states that generate high anterior cruciate ligament forces. J Orthop Res 1995; 13(6): 930-5.
52. Nunley RM, Wright D, Renner JB, Yu B, Garrett WE. Gender comparison of patellar tendon tibial shaft angle with weight bearing. Res Sports Med 2003; 11(3): 173-85.
53. Cerulli G, Benoit DL, Lamontagne M, Caraffa A, Liti A. In vivo anterior cruciate ligament strain behaviour during a rapid deceleration movement: Case report. Knee Surg Sports Traumatol Arthrosc 2003; 11(5): 307-11.
54. Hewett TE, Myer GD, Ford KR, Heidt RS, Colosimo AJ, McLean SG, et al. Biomechanical measures of neuromuscular control and valgus loading of the knee predict anterior cruciate ligament injury risk in female athletes: A prospective study. Am J Sports Med 2005; 33(4): 492-501.
55. Myer GD, Ford KR, Di Stasi SL, Foss KD, Micheli LJ, Hewett TE. High knee abduction moments are common risk factors for patellofemoral pain (PFP) and anterior cruciate ligament (ACL) injury in girls: Is PFP itself a predictor for subsequent ACL injury? Br J Sports Med 2015; 49(2): 118-22.