The Effects of Different Walking Inclinations on Knee Angle in the Frontal Plane of Patients with Varus Malalignment

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ABSTRACT

Purpose: Given the high prevalence of varus malalignment of the knee and the consequences of walking on different surfaces on this malalignment, the aim of the present study was to investigate the effect of walking inclination on knee angle in the frontal plane of patients with varus malalignment.

Methods: 18 male subjects with varus malalignment classified at grade 3 bowleg, within the age range of 19-24 years, volunteered to participate in this study. The parameters of knee angle in the frontal plane at the moments of heel contact, midstance and toe off when walking on -7.5, zero, +5 and +10 percent of treadmill inclination were calculated using three-dimensional motion analysis system with six optoelectronic cameras. Repeated measures of variance and non-parametric Friedman test were used for data analysis.

Results: The results of the present study showed that as walking inclination increases, knee angle in the frontal plane decreases. The only significant differences were related to varus angle between +10 and zero percent inclinations at the moment of midstance ($P<0.001$) and between -7.5 and zero percent inclinations at the moment of toe off ($P<0.001$) and in case of other parameters, no significant differences were observed.

Conclusion: According to the obtained results, walking on upslope surfaces, probably is a suitable solution to reduce the load exerted on the knee and prevent premature osteoarthritis in young individuals with varus malalignment.

1. Introduction

Varus malalignment of the knee is one of the most common deformities of the knee joint. This condition is a lower limb malalignment in the frontal plane which has been reported as the most common deformity of the lower limbs among male guidance school students in Tehran with the rate of 40.71 percent and other similar studies have also confirmed the prevalence of this condition in other age levels and geographical areas [1-3]. Varus malalignment of the knee is commonly associated with osteoarthritis of the medial compartment of the knee joint and it has been shown that this deformity increases the risk of progression of osteoarthritis up to four times in patients with osteoarthritis and doubles the risk of developing osteoarthritis in people who have not developed osteoarthritis yet [4, 5]. The importance of this condition in causing osteoarthritis is so remarkable that Tanamas et al [6] have introduced knee deformities as an independent risk factor in the initiation and progression of this disease. Research evidence has shown that while walking, ground reaction force to the proximal compartment of the joint passes medial to the center of the knee joint. The action of this force causes a moment which tends to keep the knee in the adduction condition [7]. In the stance phase of walking, the generated moment increases the load exerted on

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the medial compartment of the knee joint, which is associated with degeneration of articular cartilage in the medial compartment of the knee [8].

Walking, as a basic skill, comprises most of man's daily motor activity and is also one of the most popular health-related exercises and due to its importance, much research has been done about it [9]. During walking, the forces are not evenly distributed throughout the knee joint and approximately 70 percent of the total load is applied to the medial compartment of the knee joint [7, 8].

In patients with varus malalignment of the knee, due to greater moment arm of the ground reaction force, the load exerted on the medial compartment of the joint even exceeds 70 percent and turns into a factor accelerating the degeneration of the articular surfaces and development of osteoarthritis [5,7]. Considering the above issues, presenting an exercise for reducing the moment arm of the ground reaction force and consequently, reducing the load exerted on the medial compartment of the knee joint in patients with varus misalignment of the knee seems to be a necessity.

Walking on inclined surfaces is one of the most popular forms of walking which is frequently used for exercise and rehabilitation purposes. Walking on inclined surfaces increases the activity of quadriceps, hamstrings, twin muscles, and soleus which, in turn, leads to an increase in metabolism, fat burning, and the strength of the lower limbs muscles [10]. This type of walking is recommended and prescribed for fitness purposes for the elderly and people with obesity and also for knee joint rehabilitation in patients who have undergone total knee replacement [11,12].

Haggerty et al [12] studied healthy individuals during upslope walking and showed that as inclination increases, knee angle in the frontal plane changes from the varus to the valgus angle and consequently, adduction moment changes to abduction moment. These changes can have a positive impact on reduction of degeneration of articular surfaces as well as reduction of progression rate of osteoarthritis of the medial compartment. Lange et al [13] also studied healthy individuals during walking and considered slopes greater than 12% to be effective in knee rehabilitation and reduction of patellofemoral pain, but in their research, Han et al [14] showed that as walking inclination increases, varus angle of the knee also increases.

Based on the studies conducted in this field, so far there has been no research conducted specifically on the patients with varus malalignment of the knee and given the discrepancy among some of the results of these studies, it is not clear whether or not walking on inclined surfaces as an exercise is suitable for this group. Furthermore, none of these studies have examined the effects of downslope inclinations on varus angle during walking. Based on the above considerations, the aim of the present study is to investigate the effect of walking on upslope and downslope inclinations on knee angle in the frontal plane of patients with varus malalignment.

2. Materials and Methods

The statistical population of this quasi-experimental research consisted of all the male students of Shahid Bahonar University of Kerman. From the statistical population, 18 individuals were selected purposefully. Given the high prevalence of grade three varus of the knee and since these patients are more likely to develop joint diseases as compared to patients with grade one and two varus of the knee, the criteria for inclusion in research were 5 to 7.5 cm distance between the medial epicondyles of the femur [15].

Since the structural type of varus of the knee is much less influenced by corrective exercises as compared to the functional type, patients with structural varus were eliminated from the samples and eventually, considering the fact that most of the bowlegged individuals experience the compensatory mechanism of ankle pronation when walking in order to reduce the joint load exerted on the medial compartment of the knee, those individuals were selected who experienced ankle pronation when walking. The subjects had no history of surgery or fracture of the lower limbs and were in perfect health at the time of the test. Prior to conducting the research, the subjects were informed of the conditions of implementation of the research and signed informed consent form before agreeing to participate in this research.

First, the subjects' height, weight and the distance between the medial epicondyles of the femur were measured (using calipers models of Vernier, Long jaw, and Mituyoto made in Japan with the precision of 1 millimeter) and then, they were asked to walk barefooted three times on a 10-meter path at their desired pace and the tester recorded the time of walking by a chronometer. Upon completion of the three walks, the mean speed as preferred walking speed for each individual, was used for adjusting the speed of the treadmill (Tunturi brand, model J880, made in Netherlands). For data collection,

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Figure 1. Position of six optoelectronics cameras relative to the treadmill.

three-dimensional optoelectronic motion analysis system (Motion Analysis, Raptor-H Digital Real Time System, made in USA) with six cameras was used and the sampling frequency was considered to be 120 Hz (Figure 1). After preparing the cameras, three passive reflective markers with the diameter of 19 cm were placed in the desired positions in order to obtain knee angle in the frontal plane. These positions included the anterior and medial surfaces of the tibia in the distal tibial bone, tibial lump, and the midpoint of the line that connects the anterior superior iliac spine to the patella [16].

Also, in order to measure spatio-temporal parameters of subjects' walking, four markers were attached to the heel bone and the big toe of the right foot and the heel bone and the big toe of the right foot (Figure 2) [17, 18]. The markers were fixed on the body of the subjects with double-sided adhesive tape and a rubber band to prevent markers from moving during the test.

At first, in a static position, the location of these markers on each subject's body were filmed. Then, the subjects were given enough time to walk on the treadmill and adapt to walking on it. After the subjects voiced their readiness and the tester recognized that they are prepared, the treadmill speed was set to the specified pace for each subject. The subjects walked on zero, +5, +10, and -7.5 percent inclinations at preferred walking speeds and in random sequence and on each of the inclinations, after two minutes of walking, 20 seconds of recording was made. To avoid exhaustion, the subjects were given one-minute rest periods between the tests [17,18].

The recorded data were processed by using CORTEX software Version 2.5. To eliminate the noises caused by the movement of the markers, Butterworth low-pass filter with the frequency of 6 Hz was used. To reduce the amount of data, five consecutive strides were extracted from the recorded film and then the intended parameters including knee angle in the frontal plane at the moments of toe off, midstance, and heel contact were calculated using Matlab software, velocity-based treadmill algorithm, and trigonometry laws and the changes in this angle as compared to the static position were obtained for each subject [19]. In addition to the abovementioned angular parameters, spatio-temporal parameters including stance duration, swing duration, one stride duration, and cadence was also calculated.

Finally, data analysis was conducted by using SPSS software Version 22. Mean and standard deviation were used for descriptive statistics and description of the data. Regarding inferential statistics, first normality of the data was examined using Shapiro–Wilk test and then, in order to obtain significant differences between the measured parameters of walking on -7.5, +5 and +10 percent inclinations and zero percent inclination, in case of normality of the data, analysis of variance with repeated measures were used and in order to determine significant points, Bonferroni post hoc test was used and in case of lack of normality of the data, non-parametric Friedman test and Wilcoxon T test for paired samples were used. Significance level of the tests was considered to be 0.05.

3. Results

Characteristics of the subjects including age, weight, height, the distance between the medial epicondyles of the femur, and preferred walking speed have been shown in Table 1.

The values of spatio-temporal parameters have been presented in Table 2. The results did not show a significant difference between -7.5, +5 and +10 percent inclinations and zero percent inclination, which confirms that

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Figure 2. The location of the seven reflective markers on lower extremities.

Table 1. Means and standard deviations of the clinical and demographic characteristics of the individuals (N=18).

Characteristics	Mean	SD
Age (year)	21.8	1.38
Height (cm)	175.16	6.14
Weight (kg)	64.4	7.15
Distance between medial epicondyles (cm)	5.69	0.58
Preferred walking speed (km/h)	5.12	0.57

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treadmill speed during the test has been fixed for each subject.

The values of angular parameters have been presented in Table 3. The obtained results showed that, in general, as walking inclination increases, knee angle in the frontal plane decreases (also see figure 3). Significant differences were related to the parameter of varus angle at the moment of midstance between zero and +10 percent inclinations (P<0.001) and at the moment of toe off between -7.5 and zero percent inclinations (P<0.001).

4. Discussion

The aim of the present study was to investigate the effect of different walking inclinations on knee angle in the frontal plane of patients with varus malalignment. In a study similar to that of Lay et al [20], in order to minimize the effects of walking speed on the studied angular parameters, walking speed of each individual was considered to be the same on all inclinations. Lack of a significant difference between the results presented in Table 2 also indicates that walking speed on different inclinations has been under control.

In regard to knee angle in the frontal plane, most of the reported differences were not statistically significant. According to the findings of the study by Anbarian et al [21] and Stief et al [22], individuals with varus malalignment of the knee who have not developed osteoarthritis of the knee joint yet, use more electromyographic activity and co-contraction in the distal area of the knee joint in order to stabilize the joint and cope with the greater adduction moment exerted on the medial compartment of the knee during the stance phase of walking or running.

In spite of the significant difference in most of the measured angular parameters, values of knee angle in the frontal plane showed that as walking inclination increases from -7.5 to +10 percent, this angle decreases at the moments of heel contact, midstance and toe off. As inclination increases, knee joint has more flexion at the moment of heel contact as compared to normal walking and this is reversed while walking on downslope inclinations, that is, at the moment of heel contact, knee joint extension will be greater as compared to walking on a non-inclined surface [14].

As a result, while walking on downslope inclinations, knee joint is in close-packed position. In this position, force absorption capability of the joint decreased and consequently, at the moment of heel contact when the initial peak ground reaction force is exerted on the body [23], the highest amount of knee varus was observed in patients with varus malalignment of the knee as com-

Table 2. Mean ± standard deviation for spatial temporal variables.

Spatial-temporal variables	Treadmill inclination			
	-7.5%	0%	+5%	+10%
Stance time (s)	0.53 ± 0.02 P= 0.71	0.54 ± 0.03	0.55 ± 0.04 P= 1.000	0.56 ± 0.04 P= 1.000
Swing time (s)	0.40 ± 0.02 P= 1.000	0.41 ± 0.02	0.41 ± 0.02 P= 1.000	0.41 ± 0.03 P= 1.000
Cycle time (s)	0.94 ± 0.04 P= 0.323	0.95 ±0.05	0.96 ± 0.06 P= 1.000	0.97 ± 0.06 P= 0.211
Cadence (steps/min)	127.06 ±6.04 P= 0.351	124.83 ± 7.32	124.17 ± 7.99 P= 1.000	122.50 ± 7.90 P= 0.274

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Table 3. Mean ± standard deviation for knee varus angles. Angles are in degree.

Angular variables	Treadmill inclination			
	-7.5%	0%	+5%	+10%
Knee varus at heel contact	1.75 ± 1.46 P= 1.000	1.58 ± 1.72	1.42 ± 1.86 P= 1.000	1.29 ± 1.88 P= 0.992
Knee varus at midstance	0.78 ± 1.23 P= 0.601	0.74 ± 1.05	0.62 ± 1.16 P= 0.338	-0.15 ± 1.15* p≤ 0.001
Knee varus at toe off	4.69 ± 1.90* P≤ 0.001	2.72 ± 1.83	2.35 ± 1.78 P= 0.474	2.08 ± 1.79 P= 0.177

*Indicates a significant difference from the 0% inclination (P<0.05)
Positive values represent knee varus angle and positive values represent knee valgus angle.

pared with other inclinations. As upslope inclination increases, the stride mechanism changes and the joint approaches loose-packed position, force absorption capability of the joint increases and consequently, the amount of varus decreases and its subsequent adduction moment also decreases.

Therefore, the lowest varus angle was obtained while walking on a +10 percent inclination. At the moment of midstance, due to a decrease in ground reaction force, varus angle decreased as compared to the moment of heel contact and even in +10 percent inclination, this angle changed from varus to valgus. Also at the end of the stance phase and at the moment of toe off, due to secondary peak ground reaction force, varus angle increased.

These findings were in line with the findings of the study conducted by Lange et al [13] and Haggerty et al [12], which had studied the influence of incline walking on healthy individuals, and indicate that as walking inclination increases, the adduction moment applied to the medial compartment of the knee joint decreases. The amount of the adduction moment applied to the knee is influenced by the ground reaction force, the perpendicular distance between the line of action of the force and the knee joint center of rotation (moment arm), and mass and acceleration of different parts of the lower extremities. In patients with varus malalignment of the knee, due to increased knee angle in the frontal plane (bowlegs), moment arm increases which puts a greater load on the medial compartment of the knee joint.

Based on the results of the present research, as walking inclination increases, moment arm decreases and even, at some points of the walking cycle, knee adduction changes to abduction. This shows a decrease in the load exerted on the medial compartment of the knee joint.

The results of this research are not in line with the results of the study conducted by Han et al [14], which reported that as walking inclination increases, knee angle in the frontal plane also increases. Some possible reasons for this disagreement could be the use of different measurement tools, not using treadmill and not control-

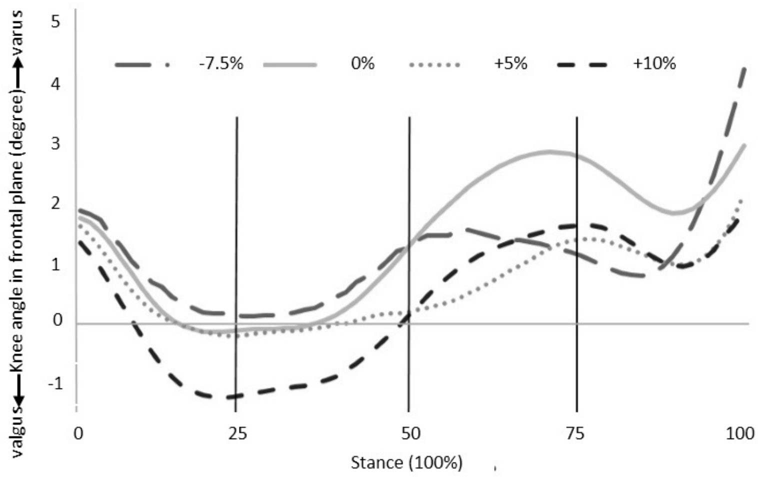

Figure 3. Mean angular variation of the knee in the frontal plane during treadmill walking at inclination of -7.5%, 0%, +5% and +10%.

ling the walking speed of the subjects participating in the study by Han et al.

Based on the findings of the present research, knee angle in the frontal plane of the patients with varus malalignment of the knee is maximum while walking on -7.5 percent inclination and minimum while walking on +10 percent inclination. Downslope inclinations can be considered a risk factor for patients with varus misalignment of the knee and on the contrary, upslope inclinations can potentially reduce the load exerted on the medial compartment of the knee joint and can be incorporated into the rehabilitation programs of patients with varus malalignment of the knee as a physical exercise.

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