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Correlation between Spatiotemporal and Kinematic Parameters of Walking with a History of Falling in Women with Osteoarthritis of the Medial Compartment of the Knee

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Original Article

Abstract

Introduction: Knee osteoarthritis (OA) is a debilitating chronic disease that leads to swelling, inflammation, and pain in the knee joints. Most falls occur while walking, and it is thought that there is a correlation between gait characteristics and the risk of falling in the elderly. The aim of the present study was to determine the correlation between the kinematic and spatiotemporal characteristics of walking and the history of falls in women with knee OA.

Materials and Methods: 60 women with unilateral OA of the knee were selected based on the research inclusion criteria in a purposeful and available manner and after filling out a written consent form, they were included in the study using a limited randomization method of block randomization type. Then, the falling history of participants was recorded. To record spatiotemporal and kinematic variables of walking, a motion analysis system was used. To measure the correlation between the spatiotemporal parameters of walking (movement and spatiotemporal data) and the history of falling, the biserial correlation coefficient was used.

Results: According to the results of the biserial correlation coefficient test, there was no relationship between spatiotemporal and kinematic factors in all three joints of the hip, knee, and ankle and the subject's history of falling.

Conclusion: No correlation was observed between walking characteristics and a history of falls in patients with knee OA. It is possible that the participants with OA symptoms may be aware of their presence and physical activity, or may limit their daily life activities. It should also be noted that the current study is retrospective and patients may underestimate or overestimate their history of falls accordingly.

Keywords: Spatiotemporal analysis; Kinematics; Knee osteoarthritis; Elderly; Falling

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Introduction

Knee osteoarthritis (OA) is a long-term and incapacitating ailment that results in swelling, inflammation, and discomfort in the knee joint. As the world population ages and the obesity crisis continues, its occurrence rises (1). Its primary clinical symptoms are discomfort and a loss of mobility (2). OA is among the leading causes of falls in older people. Those with knee OA are 30% more likely to experience a fall than those who are healthy (3).

It is common for falls to happen during walking, indicating a possible connection between walking patterns and the likelihood of falls among older individuals (4, 5). Research has shown that older adults with shorter stride lengths, longer double support (DS) times, and slower walking speeds have a higher risk of falling, even if they are generally healthy (3, 6-8).

Walking is a complex activity that involves many measurable aspects beyond just speed. These aspects can help identify individuals more likely to experience frequent falls. A study of 96 older women living in the community (72.8 ± 6.2 years old)

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showed that those who had fallen two or more times in a year had a significantly decreased cadence and increased stance phase time (9). Another study of 96 healthy and active community-dwelling women aged 70 and over found that the stage of DS was related to the prediction of frequent falls (10). However, a study of 148 older women living in the community found no relationship between spatiotemporal walking parameters and frequent falls (11).

Individuals with knee OA utilize various methods to compensate while walking. Reducing knee joint movements due to muscle weakness, pain, or deformity caused by deteriorating knee OA can cause more imbalances in controlling balance (12). Consequently, the walking mechanics of individuals with knee OA differ from those who are healthy. These individuals possess more variations in step width, step length, and DS time, ultimately reducing walking control (13). Nonetheless, information is scarce regarding the gait changes of individuals with knee OA, particularly the correlation of these modifications with the risk of falls in this specific group.

The relationship between the biomechanics of walking and falling among people with knee OA is crucial for clinical purposes. It can help in adopting preventive intervention strategies for this group of people. The kinematic and spatiotemporal characteristics of walking correlate with the history of falling in women with knee OA. Therefore, the present study aims to determine the correlation between the kinematic and spatiotemporal walking characteristics and the history of falling in women with knee OA.

Materials and Methods

In this descriptive retrospective study, participants were recruited from clinics and rehabilitation centers in Kerman City, Iran. The inclusion criteria were female gender, being 55-65 years old, having radiological signs of unilateral knee OA, chronic knee pain for at least one month, and no history of intra-articular injection in the last four months. Additionally, the patients had not taken non-steroidal anti-inflammatory drugs (NSAIDs) for at least one week before entering the study. They also had no history of trauma, injury, surgery, fracture of the lower limb, or long-term use of drugs affecting the musculoskeletal system. The classification of Kellgren and Lawrence (14) was used to determine the severity of OA.

The study included 60 women with unilateral knee OA who were specifically selected based on the entry and exit criteria. All the participants filled out a written consent form before enrolling in the study. It is worth noting that only female patients were included in this study because knee OA is more prevalent among women than men. Additionally, as previously reported, the kinematic and spatiotemporal walking characteristics differ between women and men (15). The sample size was determined using G*Power software (G*Power 3.1.9.7 freeware, University of Düsseldorf, Düsseldorf, Germany), with an alpha size of 0.05 and a statistical power of 80%, based on the study by Saelee (16). The testing process was explained to the subjects in detail. They were fully aware of the importance of the study. However, they were not informed of the study's main goal, which the researchers kept hidden. The study complied with all ethical principles and was carried out at the sports biomechanics laboratory of the Shahid Bahonar University of Kerman.

To gather information about individuals, their height and weight were collected using a tape measure and a Seca hand scale (Seca, Germany) with a precision of 0.01 kg, respectively. The researcher also examined the participants' history of falls, asking "Have you fallen in the past 12 months?". The number of falls experienced was also recorded if the answer was affirmative (17).

We used a motion analysis system called Motion Analysis (Raptor model, manufactured by Motion Analysis, California, USA) to gather information about how people walk. This system has six high-speed cameras and records at a frequency of 120 Hz. The cameras were placed in the corners of a 12 × 10-meter area, 2 meters from the ground. We used a smaller size, measuring 3 × 2 × 1.5 meters, to calibrate the cameras. We analyzed the data using Cortex software (version 2, made by Motion Analysis, California, USA) to determine spatiotemporal parameters like heel contact, mid-stance, and toe-off during the stance phase of walking.

We used a marker set called Plug-in Gait lower body models to measure the biomechanical parameters of walking in the camera area (14). Sixteen reflective markers were placed on the anatomical points of the lower limb, including the anterior superior iliac spine (ASIS), the middle of the femur, the external condyle of the knee, the middle of the leg, the external side of the ankle, the heel, and the first toe.

To collect data on how each person walks, the participants were asked to walk barefoot along a 10-meter path at their preferred speed. They were allowed to walk the path three times to become familiar with the process. For analysis purposes, three successful gait cycles from three valid trials were recorded for each patient, which the examiner visually verified. There was no significant difference in the speed of the recorded gait cycles. The average of the three successful walking tests was then calculated for each parameter. The subjects took approximately three steps before and after the calibrated space, eliminating the effect of starting and stopping (18). The calibrated space was 3 meters long, allowing the subject to take two complete steps within the area. After reviewing the recorded video, two specific steps were selected for analysis. The moment of heel contact with the ground was determined by identifying when the vertical displacement of the heel marker was at its lowest point. The separation of the first finger was determined by identifying when the horizontal acceleration of the first finger marker was at its highest point (18). These evaluations were conducted by a sports biomechanics specialist with experience in conducting kinematic and gait analysis projects.

The Cortex software version 2.5 was used to process the data obtained from the motion analysis system. A four-level Butterworth filter without phase difference with a cutoff frequency of 6 Hz was applied to smooth the biomechanical data to ensure accuracy. Various variables such as cadence, walking speed, step length, stride length, stride time, single-support (SS) and DS, separation of the opposite leg (opposite foot off), contact of the opposite foot with the ground (opposite foot contact), and the time of separation of the paw (foot off) were extracted as a percentage of the length of the walking cycle (14, 19).

To determine the movement of the lower limb and the angles of the hip, knee, and ankle joints, the coordinates of markers placed during the initial impact of the foot, mid-stance, and separation of the toe from the ground were utilized (14, 19). Each joint's flexion and extension, abduction and adduction, and internal and external rotation were recorded and analyzed through kinematic data.

The study utilized descriptive statistics, specifically mean and standard deviation (SD), to describe the data. To determine normality, the Shapiro-Wilk test was employed. The biserial correlation was used to measure the correlation between spatiotemporal and kinematic walking characteristics with a history of falling in women with knee OA. This type of Pearson's correlation coefficient determines the correlation between a quantitative variable with a normal distribution and a two-mode nominal qualitative variable. In this study, a person's history of falling, which had two values, was considered in the software as either zero or one. Zero represented the state when the person had no history of falling, while one indicated when the person had a history of falling. The spatiotemporal and kinematic variables of walking were considered quantitatively continuous. Data analysis was conducted using SPSS software version 24 (version 24, IBM Corporation, Armonk, NY). The significance level considered was 0.05. Finally, power analysis was performed using G*Power software.

Results

Sixty female patients with unilateral OA of the internal compartment of the knee joint participated in the present study. The subjects' demographic and clinical information (results related to the self-reported fall history questionnaire) is recorded and reported in table 1.

Table 1. The subjects' demographic and clinical data

Property	Value
Age (year) (mean ± SD)	59.60 ± 6.22
Height (cm) (mean ± SD)	155.00 ± 5.00
Weight (kg) (mean ± SD)	71.40 ± 2.95
Length of the involved limb (cm) (mean ± SD)	72.40 ± 4.50
BMI (kg/m^2) (mean ± SD)	29.99 ± 4.27
Severity of knee osteoarthritis in Kellgren and Lawrence scale [n (%)]	
1	
2	
3	
Falling history during the past year [n (%)]	
No	24 (40.00)
Once	14 (23.34)
Twice	22 (36.67)
Three times or more	0 (0)

SD: Standard deviation; BMI: Body mass index

Based on the self-reported history survey results, 24 of the subjects did not fall down in the last 12 months, but 36 of the subjects had this experience at least once.

Table 2 shows the results of the cross-sectional correlation test of the data related to the spatiotemporal characteristics of walking with the results of the history of falling. Based on this table, it did not confirm any relationship.

Table 3 is related to the mean and SD as well as the results of the cross-sectional correlation test of the data associated with the kinematic factors of the three hip, knee, and ankle joints during three stages of walking (initial contact, mid-stance, and toe-off) with the results of the history of falling. The table below shows no relationship between the mentioned factors and the subject's history of falling.

Table 2. Correlation of spatiotemporal characteristics with subjects' history of falling

Variable	Mean ± SD	Correlation between the variable and the number of falls during the last 12 months	P
Cadence (step/minute)	99.33 ± 10.12	-0.21	0.17
Stride time (second)	1.23 ± 0.13	0.20	0.39
Step time (second)	0.61 ± 0.09	0.13	0.25
One leg support (second)	0.55 ± 0.03	-0.17	0.13
Double leg support (second)	0.35 ± 0.01	0.21	0.34
Stride length (meter)	1.05 ± 0.11	0.17	0.57
Step length (meter)	0.52 ± 0.05	-0.23	0.53
Walking speed (meters per second)	0.81 ± 0.20	-0.11	0.60

SD: Standard deviation

Discussion

This research is the first to investigate the relationship between kinematic and spatiotemporal walking characteristics and a history of falling in women with OA of the medial compartment of the knee in Iran. However, the study did not find any correlation between these factors.

A study published in 2022 examined a large group of healthy older men and women (14). The study found that decreased stride length in men over 74 was associated with a history of falls. However, reduced walking speed was not associated with a history of falls in older men and women. In the current study, the number of participants was much less, and all participants were women with knee OA. Only 60% of them had experienced falling in the past year. The study did not find any significant relationship between spatiotemporal and kinematic walking characteristics with the history of falling in these people. This could be due to the calculation of the average joint angle. However, the study's participants suffered from mild to moderate knee OA. If the severity of OA in the participants was higher, changes in their history of falling could be recorded. This is because the progress of OA can disturb the proprioceptive sensation, an essential component of balance. This disturbance is more severe in the high severity of the disease (20, 21).

Compared to healthy individuals, people with knee OA may experience more concern about movement and physical activities, leading to a reduction in their daily activities and a lower risk of falling. In the studied group, none of the participants had fallen three times or more in the past year, while 40% had no falling experience during this period. Previous studies have revealed that slower walking speed, shorter stride length, wider stride width, and longer DS time - characteristic of walking in people with knee OA - are associated with a pre-existing fear of falling (22). These changes in gait can subsequently create sensory or motor system adaptations that help ensure safer walking conditions (23). Conversely, faster walking speeds can result in changes in the gait cycle that decrease DS time and increase gait instability, ultimately raising the risk of falling (24).

According to existing studies, there is no significant difference in walking speed between people under 70. However, after turning 70, walking speed decreases by 15% for every ten years of age increase. This decrease in speed makes people more susceptible to falling, as noted in previous studies (25-27). Despite the increasing age of the participants in the current study, there have been no significant changes in their spatiotemporal kinematic indicators or muscle strength and coordination. These factors are essential in preventing falls (28, 29). It should be noted that without a healthy control group for comparison, it is difficult to determine the exact changes relative to the general population.

Limitations

The results of the present study cannot be generalized to other age groups and men as it only focused on women aged 55-65 with knee OA. One of the limitations of the study was the small number of participants. Another limitation was the possibility of error in placing reflective markers for gait analysis. Most participants were overweight or obese, which made finding suitable bony landmarks for marker placement challenging. This problem can cause software to fail in measuring joint angles. However, to minimize skin surface movement, markers were laterally moved along the ASIS-ASIS axis by an equal amount when accurately placing them on the ASIS was difficult. The actual distance between the ASIS was also recorded and entered as subject parameters in the Cortex program. Since the age range of the participants was 55 to 65 years, the percentage of people with severe OA was lower. A significant relationship between the history of falling and spatiotemporal or kinematic indicators of walking could be observed by collecting information from people with higher severity of the disease.

Table 3. Average and standard deviation (SD) and results of the correlation test between kinematic factors and subjects' history of falling in the gait cycle

Stepping stage	Joint	Range of motion (degree)	Mean ± SD	Correlation	P-value
Initial contact	Hip	Flexion (+) Extension (-)	30.34 ± 3.11	0.23	0.48
		Adduction (+) Abduction (-)	-4.23 ± 2.94	-0.10*	0.89
		Internal rotation (+) External rotation (-)	-10.56 ± 4.88	-0.16	0.78
	Knee	Flexion (+) Extension (-)	7.77 ± 6.00	0.09*	0.94
		Varus (+) Valgus (-)	4.98 ± 4.09	0.17	0.81
		Internal rotation (+) External rotation (-)	-12.44 ± 5.60	-0.30	0.69
	Ankle	Dorsi-flexion (+) Plantar flexion (-)	6.01 ± 3.53	0.13*	0.74
		Inversion (+) Eversion (-)	-4.00 ± 1.29	0.12*	0.66
		Internal rotation (+) External rotation (-)	-3.34 ± 2.33	-0.08*	0.88
Mid-stance	Hip	Flexion (+) Extension (-)	11.78 ± 4.39	0.31	0.30
		Adduction (+) Abduction (-)	3.89 ± 1.11	0.12*	0.56
		Internal rotation (+) External rotation (-)	-13.44 ± 6.13	-0.29	0.43
	Knee	Flexion (+) Extension (-)	10.01 ± 7.88	0.24	0.39
		Varus (+) Valgus (-)	6.71 ± 4.81	0.30	0.42
		Internal rotation (+) External rotation (-)	-10.32 ± 9.13	-0.12*	0.67
	Ankle	Dorsi-flexion (+) Plantar flexion (-)	13.18 ± 4.49	0.20	0.40
		Inversion (+) Eversion (-)	-4.59 ± 3.90	0.11*	0.75
		Internal rotation (+) External rotation (-)	-2.46 ± 1.86	0.07*	0.86
Toe-off	Hip	Flexion (+) Extension (-)	-8.20 ± 3.44	0.33	0.49
		Adduction (+) Abduction (-)	-6.90 ± 2.73	0.25	0.51
		Internal rotation (+) External rotation (-)	-5.00 ± 2.30	0.29	0.55
	Knee	Flexion (+) Extension (-)	30.09 ± 6.56	0.34	0.43
		Varus (+) Valgus (-)	9.11 ± 3.12	0.26	0.63
		Internal rotation (+) External rotation (-)	-8.82 ± 7.23	-0.20	0.44
	Ankle	Dorsi-flexion (+) Plantar flexion (-)	-7.03 ± 3.34	-0.23	0.52
		Inversion (+) Eversion (-)	-4.99 ± 4.30	-0.08*	0.88
		Internal rotation (+) External rotation (-)	-3.59 ± 1.71	0.26	0.49

*0.6 < correlation < 0.8
SD: Standard deviation

The lack of a healthy control group matched with people with OA makes it difficult to conclude whether OA is related to a history of falls. Besides, the history of falling was checked only based on the personal reports of the participants. Using wearable fall recorders and conducting a similar cohort study could lead to better conclusions.

Recommendations

It is recommended that a cohort study be conducted in the future, using wearable devices to detect and record falling experiences. Additionally, it would be helpful to repeat the current study while recording information from healthy participants matched with the group with OA (using a case-control design) to draw better conclusions. It would also be beneficial to determine the correlation between gait characteristics and a history of falls in people with severe knee OA in both men and women. Furthermore, considering the role of muscles in maintaining balance, measuring the correlation between the kinetic characteristics of walking and the history of falls in older people is suggested.

Conclusion

This research investigated the connection between the kinematic and spatial-temporal variables of walking and the incidence of falls in individuals with knee OA. The findings revealed that there was no correlation between spatiotemporal and kinematic characteristics and the history of falls in patients with knee OA. It is conceivable that individuals with OA symptoms were aware of their condition and physical activity or might have limited their daily life activities. In addition, it should be noted that the study was retrospective, and the patients might not have accurately reported their history of falls.

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Authors' Contribution

Study design and ideation: Fereshteh Sabet
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Maintaining the integrity of the study process from the beginning to the publication, and responding to the referees' comments: Shayan Haj Ebrahimi, Ehsan Ebrahimipour, Fereshteh Sabet, Fariborz Mohammadipour

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Conflict of Interest

Authors do not have a conflict of interest.

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