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Effects of severity of osteoarthritis on the temporospatial gait parameters in patients with knee osteoarthritis

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Objective: The aim of this study was to investigate the differences in temporospatial parameters in according to severity of knee osteoarthritis (OA).

Methods: The study included a total of 110 subjects with no orthopedic or neurologic disease that might affect gait were divided into three study and one control groups. Eighty subjects (mean age: 53.13±6.78 years) were diagnosed with bilateral knee OA and divided into groups according to Kellgren-Lawrence radiologic scale: the Phase 1 group included 29 subjects, Phase 2, 28 subjects, and Phase 3, 23 subjects. The control group was composed of 30 healthy subjects (25 females, 5 males; mean age: 41.50±5.79 years). Temporospatial gait data were evaluated using a gait analysis system.

Methods: There were no significant differences in all temporospatial parameters between the control group and the Phase 1 and 2 OA groups (p>0.05). There was a significant decrease in cadence, gait velocity, stride length and step length (p<0.008) and a significant increase in stride time, double support time, step time, single support time and stance phase length in patients with Phase 3 knee OA compared to the other groups (p<0.008).

Conclusion: Changes in temporospatial parameters of patients with Phase 3 knee OA may be correlated with loss of gait stabilization and increase in risk of falling. In subjects with knee OA, gait stabilization and balance loss must be examined and evaluated in terms of risk of falling and necessary precautions must be taken.

Key words: Biomechanics; knee osteoarthritis; severity of osteoarthritis; temporospatial parameters

Osteoarthritis (OA) is a degenerative disease characterized by the progressive destruction of joint cartilage and is especially seen in weight-bearing joints such as the knee.[1] The clinical symptoms of OA such as pain, joint stiffness, lessening of joint movements and muscle strength can lead to changes in kinetics, kinematics and temporospatial parameters of gait.[2-5] Due to improvements in three-dimensional gait analysis technologies, studies in the last 10 years have led to a greater understanding of these changes. Many studies exhibit kinetic changes such as an increase in peak knee adductor moment, decreases in knee extensor moment, knee internal rotation moment and hip adductor moment and kinematic changes such as decreases in knee and hip flexion.[2-9]

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Although detailed investigations on changes in kinetic and kinematic values in subjects with knee OA have been conducted by many researchers, changes in temporospatial parameters were investigated using only a few parameters. In their study on subjects with knee OA, Huang et al. reported no differences between the healthy and knee OA groups in terms of velocity, cadence and step length parameters.[6] On the other hand, Kiss found significant differences between the healthy and knee OA groups in terms of cadence, velocity, double support phase duration parameters, but stated that there were no differences in terms of step width parameter.[7] Similarly, Kaufmann et al. reported a decrease in velocity in subjects with knee OA.[8] In their study on subjects with knee OA, Mündermann et al. ascertained that there was an increase in velocity of subjects with knee OA compared to healthy subjects.[9] A review of the literature showed the following; temporospatial values were investigated using very few parameters, there is no consensus on changes in these parameters, current changes are not discussed adequately, and there is insufficient data about other changes in temporospatial parameters.

Changes that occur in temporospatial parameters during the progression of knee OA may correlate with a decrease in gait stabilization and inadequacy of daily activities. Studies on geriatric subjects point to a decreasing step length and velocity, increasing stance phase and step width as signs of gait stabilization loss.[10,11] Gait stabilization losses correlate with inadequacy of daily activities and increase the risk of falling.[10,12] Therefore, understanding the changes which occur in temporospatial parameters during progression of knee OA might help in determining a patient's needs and deciding on treatment approaches.

The purpose of this study was to investigate the changes in temporospatial parameters caused by knee OA severity. An additional aim was to investigate the potential differences between dominant and non-dominant extremities of subjects with knee OA in terms of temporospatial parameters.

Patients and Methods

The study group included 80 subjects (66 females, 14 males; mean age: 53.13±6.78, range: 40 to 65 years; 73 right-dominate and 7 left-dominate) diagnosed with bilateral knee OA and a control group of 30 healthy subjects (25 females, 5 males; mean age: 41.50±5.79, range: 28 to 50 years). Diagnosis of OA was made through history, inspection and radiologic assessments conducted at the Hacettepe University Physical Medicine and Rehabilitation Department. Subjects were classified according to the Kellgren-Lawrence radiological classification system into 3 subgroups; 29 subjects in the Phase 1 Group, 28 in the Phase 2 Group and 23 in the Phase 3 Group. Only patients diagnosed with OA of the same stage according to the Kellgren-Lawrence radiological classification system in both knees were included in the study. Inclusion criteria were; no history of previous lower extremity surgery, major trauma, tendinopathy, bursitis, orthopedic knee injuries such as ligament and meniscus injuries, neurological or cardiopulmonary diseases which might affect the patient's gait, serious hearing, sight or speech defects, and rheumatic diseases such as osteoarthritis, gout, rheumatoid arthritis involving other joints in the lower extremities. The control group was composed of 30 healthy subjects (25 females, 5 males; mean age: 41.50±5.79 years).

Approval was obtained from the Hacettepe Uni-

Table 1. Demographic characteristic of subjects participated in study.

	Control group (n=30)	Knee OA group (n=80)			
		Phase 1 (n=29)	Phase 2 (n=28)	Phase 3 (n=23)	
	Mean±SD	Mean±SD	Mean±SD	Mean±SD	p*
Age (year)	41.50±5.79	53.34±6.64	52.75±7.27	53.34±6.60	0.003
Height (cm)	1.59±0.09	1.59±0.07	1.59±0.08	1.57±0.07	0.774
Weight (kg)	82.23±9.34	75.88±13.23	77.39±11.96	80.38±11.97	0.153
BMI (kg/m²)	32.65±4.43	29.83±5.05	30.62±5.01	32.54±4.86	0.079
Gender					
Female	25	22	24	20	
Male	5	7	4	3	
Dominant extremity					
Right (n=100)	27	27	25	21	
Left (n=10)	3	2	3	2	

*Kruskal-Wallis test.

versity Non-Interventional Clinical Researches Ethics Board. Informed consent forms provided by the same board were obtained from all patients.

Gait analysis records were captured in the Hacettepe University Physical Medicine and Rehabilitation Department Gait Analysis Laboratory using 6 high-speed 50 Hz JAI (Java Advanced Imaging) infrared digital cameras and 2 force plates (Bertec Force Plate; Bertec Corp., Columbus, OH, USA) on a 8x4 m gait road. Gait analysis on subjects with knee OA were assessed by the same physical therapist.

Data analysis was carried out using the Vicon gait analysis system (Workstation Version 4.0; Vicon, Oxford, UK). Joint central points and segmental coordinations were identified in accordance with the Davis' anthropometrics model.[13] Reflective indicators placed on certain anatomical regions of the subjects were placed in accordance with the Vicon Clinical Manager protocol.[14] Temporospatial values of gait were calculated by taking the arithmetic mean of 5 records captured on the same day. When different values were taken for two lower extremities in cadence, double step length, double step time, double support time and step width parameters, the mean of these two values were calculated as one.

Statistical analyses were performed using SPSS for Windows v.15. (SPSS Inc., Chicago, IL, USA) software. Variables were investigated using visual (histograms, probability plots) and analytical methods (Kolmogorov-Smirnov or Shapiro-Wilk's test) to determine distribution. Demographic data and gait analysis parameters were assessed with descriptive analysis and shown as mean±standard deviation (SD). As the temporospatial parameters and demographic data (age, height, weight and BMI) measurements were not normally distributed, the Kruskal-Wallis test was conducted to compare these parameters and ordinal knee OA phase variables. The Wilcoxon test was used when comparing non-normally distributed dominant and non-dominant extremity data. Correlation coefficients for relations between parameters and statistical significance were calculated using the Spearman test. An overall 5% Type 1 error level was used for inter statistical significance.

When there was a difference between groups according to the Kruskal-Wallis test, the Mann-Whitney U test was used in all pair comparisons to determine which group caused this difference. Statistical results were assessed using the Bonferroni correction. Statistical significance total Type 1 percentage error was taken as 0.8% (5/6%).

Results

Mean age was 53.13±6.78 in subjects with knee OA and 41.50±5.79 for subjects in the control group. Comparison of ages of subjects in the control group with other groups revealed that they were statistically significantly lower ($p<0.008$), and that there were no differences among other groups in terms of age ($p>0.05$). There were no significant differences in height, weight and BMI values between groups ($p>0.05$). Demographic characteristics of subjects included in this study are shown in Table 1.

There were no significant differences in the temporospatial parameters of cadence, velocity, double step length, double step time, double support time, step length and

Table 2. Comparison of temporospatial parameters among groups and paired comparison.

	Cadence (step/min)	Velocity (m/sec)	Double step length (m)	Double step time (sec)	Double support time (sec)	Step width (m)
	Mean±SD	Mean±SD	Mean±SD	Mean±SD	Mean±SD	Mean±SD
Control Group	114±7.51	1.08±0.10	1.13±0.10	1.05±0.07	0.26±0.03	0.20±0.04
Phase 1 Knee OA	109±10.87	1.03±0.19	1.12±0.14	1.11±0.12	0.28±0.07	0.20±0.03
Phase 2 Knee OA	111±6.65	1.02±0.13	1.10±0.12	1.08±0.07	0.28±0.04	0.20±0.04
Phase 3 Knee OA	99±12.06	0.84±0.04	0.99±0.18	1.23±0.15	0.36±0.09	0.19±0.03
p^1	□0.001*	□0.001*	0.008*	□0.001*	□0.001*	0.85
p^2						
Control vs Phase 1 OA	0.027	0.246	0.785	0.029	0.335	-
Control vs Phase 2 OA	0.051	0.045	0.279	0.049	0.093	-
Control vs Phase 3 OA	□0.001†	□0.001†	0.001†	□0.001†	□0.001†	-
Phase 1 OA vs Phase 2 OA	0.666	0.626	0.346	0.666	0.604	-
Phase 1 OA vs Phase 3 OA	0.005†	0.001†	0.006†	0.004†	□0.001†	-
Phase 2 OA vs Phase 3 OA	□0.001†	0.001†	0.007†	□0.001†	□0.001†	-

p^1: Kruskal-Wallis test (comparison of 4 groups); p^2: Mann-Whitney U test (paired comparison of groups). *$p<0.05$, Kruskal-Wallis test; $^{\dagger}p<0.008$, Mann-Whitney U test (assessed with Bonferroni correction and statistical significance level was accepted as $p<0.008$).

Table 3. Comparison of step length, single step time and single support time between dominant and non-dominant extremities, among groups and paired comparison of groups.

	Step length (m)			Single step time (sec)			Single support time (sec)		
	Dominant	Non-dominant	p^3	Dominant	Non-dominant	p^3	Dominant	Non-dominant	p^3
	Mean±SD	Mean±SD		Mean±SD	Mean±SD		Mean±SD	Mean±SD	
Control Group	0.58±0.05	0.55±0.06	0.006*	0.53±0.04	0.52±0.04	0.128	0.39±0.03	0.40±0.04	0.762
Phase 1 Knee OA	0.57±0.05	0.54±0.08	□0.001*	0.55±0.06	0.55±0.06	0.832	0.41±0.04	0.42±0.04	0.312
Phase 2 Knee OA	0.56±0.07	0.54±0.07	0.268	0.54±0.04	0.54±0.04	0.388	0.40±0.03	0.40±0.03	0.726
Phase 3 Knee OA	0.51±0.09	0.49±0.07	0.079	0.62±0.08	0.60±0.07	0.06	0.42±0.04	0.45±0.06	0.039*
p^1	0.008†	0.015†		□0.001†	□0.001†		0.013†	0.004†	
p^2									
Control vs Phase 1 OA	0.538	0.849		0.075	0.024		0.018	0.058	
Control vs Phase 2 OA	0.187	0.378		0.112	0.012		0.386	0.969	
Control vs Phase 3 OA	0.001‡	0.002‡		□0.001‡	□0.001‡		0.001***	0.007‡	
Phase 1 OA vs Phase 2 OA	0.527	0.631		0.517	0.898		0.261	0.035	
Phase 1 OA vs Phase 3 OA	0.005‡	0.004‡		0.003‡	0.003‡		0.305	0.322	
Phase 2 OA vs Phase 3 OA	0.007‡	0.007‡		□0.001‡	□0.001‡		0.035	0.004‡	

p^1: Kruskal-Wallis test (comparison of 4 groups); p^2: Mann-Whitney U test (paired comparison of groups); p^3: Wilcoxon test (comparison of dominant and non-dominant extremities). *$p<0.05$, Wilcoxon test; †$p<0.05$, Kruskal-Wallis test; ‡$p<0.008$, Mann-Whitney U test (assessed with Bonferroni correction and statistical significance level was accepted as $p<0.008$).

Table 4. Comparison of contralateral foot contact and foot-off, percent of stance phase length between dominant and non-dominant extremities, among groups and paired comparison of groups.

	Contralateral foot contact (%)			Contralateral foot-off (%)			Stance phase length (%)		
	Dominant	Non-dominant	p^3	Dominant	Non-dominant	p^3	Dominant	Non-dominant	p^3
	Mean±SD	Mean±SD		Mean±SD	Mean±SD		Mean±SD	Mean±SD	
Control Group	49.40±1.18	50.97±1.07	0.001*	12.37±1.84	12.62±2.14	0.794	62.52±2.26	62.91±1.89	0.261
Phase 1 Knee OA	49.74±1.59	51.05±1.45	0.030*	12.36±2.25	13.14±2.33	0.127	62.49±1.96	63.47±1.89	0.408
Phase 2 Knee OA	50.08±1.48	50.00±1.52	0.374	12.88±2.46	12.92±1.75	0.99	63.04±2.17	63.06±2.25	0.895
Phase 3 Knee OA	50.16±1.81	50.13±1.63	0.961	14.97±2.89	14.20±2.05	0.085	63.89±2.52	65.96±2.84	0.019*
p^1	0.116	0.212		0.067	0.005†		0.074	0.005†	
p^2									
Control vs Phase 1 OA	-	-		-	0.467		-	0.59	
Control vs Phase 2 OA	-	-		-	0.87		-	0.792	
Control vs Phase 3 OA	-	-		-	0.004‡		-	0.001‡	
Phase 1 OA vs Phase 2 OA	-	-		-	0.492		-	0.782	
Phase 1 OA vs Phase 3 OA	-	-		-	0.005‡		-	0.006‡	
Phase 2 OA vs Phase 3 OA	-	-		-	0.007‡		-	0.007‡	

p^1: Kruskal-Wallis test (comparison of 4 groups); p^2: Mann-Whitney U test (paired comparison of groups); p^3: Wilcoxon test (comparison of dominant and non-dominant extremities). *$p<0.05$, Wilcoxon test; †$p<0.05$, Kruskal-Wallis test; ‡$p<0.008$, Mann-Whitney U test (assessed with Bonferroni correction and statistical significance level was accepted as $p<0.008$).

single step time between the control group, Phase 1 and Phase 2 knee OA groups (p>0.05). There was a significant decrease in cadence, velocity, double step length and step length (p<0.008) and a significant increase in double step time, double support time and single step time (p<0.008) in the Phase 3 knee OA group. While there was no significant difference in stance phase length parameter in the dominant extremity between groups (p>0.05), there was a significant increase in the non-dominant extremity in the Phase 3 knee OA group (p<0.008) (Tables 2 to 4).

Step width and contralateral foot contact were similar in all groups (p>0.05). There was a significant increase in the single support time of the non-dominant extremity in the Phase 3 knee OA group than the Phase 2 and control groups (p<0.008) and in the dominant extremity in the Phase 3 OA group compared to the control group (p<0.008) (Tables 2 to 4).

There was a statistically significant increase in non-dominant extremity contralateral foot-off parameter values of Phase 3 knee OA group compared to the other groups (p<0.008). Dominant extremity values in this parameter were similar for all groups (p>0.05).

There were no statistically significant differences between the dominant and non-dominant extremity single step time and contralateral foot-off parameters in all groups (p>0.05). When the dominant and non-dominant extremities of the control group and Phase 1 knee OA group were compared, a statistically significant increase was determined in step length and a significant decrease in contralateral foot contact parameters (p<0.05). There were no differences between the dominant and non-dominant extremity's single support time and stance phase length parameters of the control, Phase 1 and Phase 2 knee OA groups (p>0.05). Single support time and stance phase length parameters were higher in the non-dominant extremity than the dominant extremity in the Phase 3 knee OA group (p<0.05) (Tables 3 and 4).

There was a strong relation between velocity and double step length (r=0.85, p<0.001). A strong negative correlation was found between velocity and double support and double step times (r=-0.74, p<0.001) and between velocity and single step time (r=-0.71, p<0.001). A moderate negative correlation was found between velocity and single support time (r=-0.44, p<0.001). While there was a very strong relation between double step time and double support time (r=0.84, p<0.001), the correlation between double step time and single support time was weak (r=0.39, p<0.001). In addition, there was a strong negative correlation between double support time and cadence (r=-0.89, p<0.001) and between double support time and stance phase length (r=0.82, p<0.001).

Discussion

This study reported changes in temporospatial parameters of subjects with knee OA and determined a significant decrease in velocity in subjects with Phase 3 knee OA. Similarly, double step length and step length parameters were significantly decreased in the Phase 3 group, while there were no significant differences between other groups. Our results were in line with most studies in the literature.[5,7,15,16] In contrast, Huang et al. reported decreased velocity and double step length in subjects with mild and severe knee OA compared to healthy subjects, although this difference was not significant.[6] Mündermann et al. reported a statistically insignificant increase in velocity in subjects with knee OA subjects compared to healthy subjects.[9] In a study by Kılıçoğlu et al., velocity was found lower in knee OA patients than in the healthy group, while step length was similar.[17] The different results in the literature may be caused by the low number of subjects evaluated in those studies[6,9] and the lack of a healthy control group from the study.[17]

The most important kinetic change seen in knee OA is the increase in peak knee adductor moment.[2,3,5-9] The relation between the decrease in velocity and the decrease in knee adductor moment has been presented in the literature.[3,18] A decrease in velocity and double step length may be the compensatory mechanism to the decrease in peak knee adductor moment. Many studies have shown a correlation between decreasing velocity and moments in the sagittal plane and in knee and hip flexion angles.[18-22] Such changes might be an important factor increasing the risk of falling in older patients with knee OA.

There were no significant differences in the temporospatial parameter of step width parameter among groups. Similar to results reported in the literature,[6,7,23] this result shows that, despite biomechanical changes such as varus deformity frequently seen in knee OA, no changes in step width and normal step width persisted.

A significant increase was determined in double step time, single step time, double support time, cadence and stance phase length of the non-dominant extremity in the Phase 3 group as compared to other groups. Similarly, Kiss reported increased double support time in parallel with OA severity.[7] Astephen et al. found that stance phase length and double step time increased in moderate (Phase 2) and severe (Phase 3-4) knee OA groups compared to the healthy group.[5] Harding et al. ascertained that stance phase length and double step time increased in knee OA subjects.[15] Kılıçoğlu et al. determined an increase in double support time and stance phase length of knee OA subjects.[17] Correlation analysis showed that the increase in double support time might be an important reason for the decrease in velocity and increase in double step time and stance phase length. These results lead us to believe that the increase in double support time is a compensatory mechanism which decreases joint loading by transferring dynamic joint loading to both lower extremities during gait.

Some studies in the literature reported that temporospatial parameter changes might affect gait stabilization or be a sign of gait stabilization loses.[10,11] In their study, Hamacher et al. found a decrease in step length and velocity and an increase in stance phase and step width in subjects who had a falling history compared to those that did not.[10] The decrease in step length and velocity and the increase in stance phase might be considered a sign of increasing falling risk in Phase 3 knee OA. McAndrew Young et al. determined that decreases in step width result in a decrease in mediolateral and anteroposterior stabilization and decreases in step length cause a decrease in anteroposterior stability.[24] The decrease in step length might be another factor causing an increase in anterior falling tendency by decreasing anteroposterior stabilization in Phase 3 knee OA.

Additionally, there was a significant increase in single support time and stance phase length of the non-dominant extremity compared to the dominant extremity in Phase 3 OA. These subjects prefer loading on the non-dominant extremity rather than loading on the dominant one. Many studies indicated a weak correlation between clinical and radiological findings.[25,26] Therefore, we believe that the dominant extremity might have more clinical affections such as pain, instability and joint stiffness compared to non-dominant extremity, despite the presence of radiographical bilateral Phase 3 knee OA.

Our results suggest that the severity of OA affects temporospatial parameters as there were significant differences in the Phase 3 group but none in the Phase 1 and 2 OA groups when compared to the healthy group. Studies in the literature show that increased OA severity results in greater differences in temporospatial parameters and other gait parameters.[3,7,20,27] Kiss reported that cadence, velocity and kinematics decreased, while the severity of OA increased.[7] In similar studies comparing severe knee OA to mild knee OA, knee adductor moment was reported to be higher in subjects with severe knee OA, which has been shown to result from the distortion of mechanic joint arrangement.[3,9,27] Nagano et al.[28] reported grater decreases in knee flexion angle and changes in knee adductor angle during gait with increasing knee OA severity. The authors claimed that these changes were caused by increasing pain and decreasing gait stabilization and knee extension strength. Some studies in the literature have shown a positive correlation between decreasing knee flexion and increasing severity of knee OA.[5] Studies in the literature and our results show greater presence of compensatory mechanisms which emerge due to the various distortions of gait caused by increasing pain and disability and the decreasing neuromuscular control and deterioration of biomechanics arrangement due to increasing OA severity of OA.

The difference in mean age of subjects in the control group from the OA groups can be considered a limitation of this study. However, as there were no significant differences in all parameters when comparing the control group with the Phase 1 and 2 groups, the mean age did not affect the results of the study or had only limited effects. In addition, the study included only Phase 1, 2 and 3 knee OA. The addition of a Phase 4 knee group might have revealed more information on changes in temporospatial parameters in patients with knee OA. The results of this study showed that differences in temporospatial parameters may be correlated with gait stabilization and balance loss. Further studies including Phase 4 knee OA subjects investigating gait stabilization and balance loss and correlating findings with differences in temporospatial parameters are needed.

In conclusion, while there were no significant differences in all temporospatial parameters between the healthy group and the Phase 1 and 2 knee OA groups, cadence, velocity, double step length, single step length parameters were significantly lower in subjects with Phase 3 OA. Additionally, there was a significant increase in double step time, double support time, single step time, single support time, and stance phase duration in the Phase 3 group compared to the other groups. In this group of patients, the decrease in double step length and the increases in double support time, double step time, single step time and single support time were correlated with the decrease in velocity. Although subjects younger than 65 of age were included in the study, the decrease in velocity and step length and increase in stance phase duration in the Phase 3 OA group suggest important proofs regarding gait stabilization and balance affection in this patient group. Thus, gait stabilization and balance loss must be examined in subjects with knee OA. Necessary measures such as living space arrangement and exercises to increase balance and stabilization must be taken in order to decrease the risk of falling.

Conflics of Interest: No conflicts declared.

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