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Original Article

Does the lower extremity alignment affect the risk of falling?

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ABSTRACT

Objectives: This study aims to investigate the effects of knee and foot alignments on the risk of falling.

Patients and methods: Between April 2016 and December 2016, a total of 74 individuals (24 males, 50 females; mean age 32.2±4.9 years; range 18 to 65 years) were included in the study. The knee Q angle and Chippaux-Smirak Index (CSI), Arch Index, and foot progression angle (FPA) evaluated by pedobarography were used for the assessment of the lower extremity alignment. The fall risk was evaluated by the Fall Index, Fourier 56 Index (F56), and Stability Index.

Results: The fall index was found to be correlated with the Q angle, CSI, the Arch index, and FPA ($p<0.05$). Q angle, Arch Index, and FPA which were explained 40% of the variance of the fall index. The Q angle was correlated with F56 and the stability index at the most position ($p<0.05$). The CSI was correlated with the F56 and the stability index at two and three positions, respectively ($p<0.05$); however, the Arch Index and FPA were not correlated with the F56 and Stability Index at any of the eight positions ($p>0.05$). According to the categorical regression analysis, the Q angle was the most effective on the F56 and Stability Index.

Conclusion: Our study results suggest that lower extremity malalignment increases the risk of falling. We believe that the risk of falling can be decreased by the reduction of these malalingments and, thus, mortality and morbidity associated with the fall can be reduced as well.

Keywords: Arch Index; Chippaux-Smirak Index; falling; foot progression angle; pedobarography; Q angle.

Postural control is the spatial control of the body position with the aim of providing balance.[1] This control is maintained by regulating the peripheral stimuli from the somatosensory, visual, and vestibular system in the central nervous system and producing muscular motor responses. As a result, falling is prevented by balancing the movement of the center of gravity on the plantar surface at the weight-bearing position.[2] Center-of-pressure (COP) excursions are calculated through the ground reaction force and are the indicative of postural control.[3] Stability disorders may cause disabilities and even falls which can lead to serious morbidities.[4-6] Falling is one of the most critical events preventing the participation of the individual from social life and reducing the capability of self-care.[7] Therefore, it is an important public health issue regarding its medical end economic consequences. There are at least two risk factors for falling and the risk increases with increasing risk factors in individuals with the history of falling.[8] Therefore, identifying the variables affecting postural stability is of utmost importance to prevent falls.

The lower extremity plays an important role in various static and dynamic activities such as standing, walking, running, and swimming.[9] Therefore, the alignment disorders of this region can affect stability. One of the commonly used parameters in the assessment of biomechanical alignment of the lower extremity is the Q angle of the knee. This angle was first defined by Brattström.[10] Using this approach, 10° to 20° for females and 6° to 10° for males are accepted normal. The deviations of the Q angle are named as genu varum or genu valgum of the knee joint. The Chippaux-Smirak Index (CSI), Arch Index, and the Foot Progression Angle (FPA) are useful for the biomechanical evaluation of the alignment of the foot.[11] The changes in the CSI and Arch Index indicate flat foot or pronation and cavus foot or supination.

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In addition, FPA is the angle between the foot and the progression line, and values between -3° and +20° are accepted normal.[12] Higher values indicate "out-toeing," while lower values indicate "in-toeing".[13]

Several studies have shown that change in the alignment of the lower extremity plays a role in the injury formation.[14-17] In addition, the effects of some changes in the alignment of the foot on the postural excursions have been also investigated.[3,18-20] However, the direct effect of lower extremity alignment on the risk of falling has not been emphasized. Indeed, the knee and foot alignments play a significant role in the lower extremity functions and daily living activities. Therefore, in the present study, we aimed to investigate the effects of foot and knee alignments on the risk of falling in healthy individuals.

PATIENTS AND METHODS

In this cross-sectional study, a total of 217 individuals between the ages of 18 and 65 years were screened between April 2016 and December 2016. Those who had any vestibular and visual problems and neurological or orthopedic disorders in the lower extremity, who underwent ankle, foot, and knee surgery, those with lower extremity pain leading to walking difficulty, and those who received medications disrupting the balance control were excluded. As a result, a total of 74 individuals (24 males, 50 females; mean age 32.2±4.9 years; range 18 to 65 years) were included in the study. The study was approved by the institutional Ethics Committee (2014/499). A written informed consent was obtained from each participant. The study was conducted in accordance with the principles of the Declaration of Helsinki.

Demographic characteristics such as age, sex, height, and weight and the history of falling of all participants were recorded. The body mass index (BMI) was calculated as weight in kilograms divided by the square of height in meters (kg/m^2). Postural sway and risk of falling were assessed using the tetra-ataxiometric posturography (Tetrax*-Sunlight medical Ltd., Ramat Gan, Israel). The device was calibrated before the study. The participants were assessed in eight different positions by spending 32 sec on each position (Table 1). The Fall Index, Fourier Index, and Stability Index scores were calculated from the obtained data by Tetrax* software (Tetrax-Sunlight medical Ltd., Ramat Gan, Israel). The Fall Index is calculated with a proprietary algorithm, which provides varying weights to different parameters for the balance results. It is an indicator of the risk of falling and divided into three groups: 0-36 indicate minimal risk of falling; 37-58 indicate moderate risk; and 59-100 indicate high risk.[21] The Fourier Index is an analysis of postural sway using different frequencies. The Tetrax* software subdivides postural sways into four categories as follows: F1: low frequencies (below 0.1 Hz), F2-4: lower-to-medium frequencies (0.1-0.5 Hz), F5-F6: high-to-medium frequencies (0.5-1 Hz), and F7-F8: high frequencies (above 1 Hz). The sway at a high-to-medium range (0.5-1Hz) (F5, F6) indicates somatosensory response mediated by the motor function of the lower extremities. The Stability Index measures the amount of sway over the four plates and is an indicator of the general stability. Higher index scores reflect more unstable posture.[21]

The Q angle was used to evaluate the biomechanical alignment of the knee. It was measured with a lengthened arm 360° plastic universal goniometer. The participant was positioned in supine position with toes pointing vertically (knee extended and quadriceps muscle relaxed). The center of the patella, the tibial tuberosity, and the anterior superior iliac spine were labeled with a marker. The pivot of the goniometer was placed on the center of the patella. The long arms of the goniometry were placed on the tibial tuberosity and the anterior superior iliac spine. The intersected angle was regarded as the Q angle.[22] The measurement was performed three times in the dominant side of the knee and mean values were calculated.

The biomechanical properties of the foot were measured using pedobarography (RSscan International, Olen, Belgium). The participant was asked to stand with bare feet on a 0.5 m pressure-sensitive platform and to walk with normal steps across this platform embedded in the middle of a 3-m-long walkway.[23] The measurements were repeated twice and mean value of the two measurements was recorded as the final score and included in the analysis. In dynamic measurements, the foot axis was, then, divided into three equal lengths to divide the footprint into a heel, midfoot, and forefoot area. The Arch Index was calculated as the ratio midfoot area divided by the whole footprint area, excluding toes. This index is a useful indicator of foot type to be a valid clinical means.[24] The CSI is measured by dividing the value of the narrower zone of the midfoot by the value of the parallel line on the wider zone of the forefoot and multiplying by 100.[11] In the static measurement, the foot axis line from the second toe to the middle of the heel was drawn in the footprint. The FPA was derived as the angle in the transverse plane between the foot vectors (second metatarsal to the posterior middle calcaneous).[12]

Table 1. Eight positions on the tetra-ataxiometric posturography

1. Looking straight ahead while upright, with the hands on the side, and the feet within the marked area.
2. Same position, with closed eyes.
3. Same position, with the eyes open, and a pillow under the feet.
4. Same position, with the eyes closed, and a pillow under the feet.
5. Same position, with the head, turned 45° to the right-hand side, and the eyes are closed.
6. Same position, with the head turned 45° to left-hand side and eyes are closed.
7. Same position, with the head, turned 30° to the upside, and the eyes are closed.
8. Same position, with the head, turned 30° to the downside, and the eyes are closed.

Statistical analysis

Statistical analysis was performed using the IBM SPSS version 22.0 software (IBM Corp., Armonk, NY, USA). Descriptive statistics were expressed in mean and standard deviation (SD), and median (min-max) values. Compliance with the normal distribution of the quantitative data was examined using the Shapiro-Wilk test. The correlations between the quantitative variables were analyzed using the Pearson's correlation analysis. The categorical regression analysis was used to identify the factors which would affect the Fall Index, F56, and Stability Index. A *p* value of <0.05 was considered statistically significant.

Table 2. Descriptive statistics for Q angle, Chippaux-Smirak Index, Arch Index, and foot position angle

	Mean±SD	Median	Range
Fall index	38.5±28.5	32.0	6-100
Q angle	9.6±3.2	8.5	4-17
Chippaux-Smirak index	30.7±8.7	31.0	15-53
Arch index	0.3±0.1	0.32	0.21-0.42
Foot position angle	12.9±7.1	12.6	0.09-33.2

SD: Standard deviation.

RESULTS

Of the participants, the mean BMI was 26.1±4.3 (median: 25.8) kg/m^2. Only seven participants had a history of falling. The mean and median values of the Fall Index, Q angles, CSI, Arch Index, and FPA are shown in Table 2. The correlation between age, sex, and BMI and the Fall Index, Q angle, CSI, Arch Index, and FPA was analyzed. The age and BMI were not correlated with the Fall Index, Q angle, CSI, Arch Index, and FPA (p>0.05). Furthermore, there were no

Table 3. Correlations between Q angle, Chippaux-Smirak Index, Arch Index and foot position angle and Fourier Index 56 and Stability Index in eight different positions

	Q angle	CSI	Arch index	FPA
Fall Index	0.461**	0.310**	-0.371**	-0.294*
Eyes open				
Fourier Index 56	0.164	0.061	-0.090	-0.087
Stability Index	0.179	0.051	-0.134	-0.103
Eyes close				
Fourier Index 56	0.460**	0.180	-0.183	-0.131
Stability Index	0.451**	0.171	-0.149	-0.136
Pillow under the feet and eyes open				
Fourier Index 56	0.403**	0.188	-0.124	-0.088
Stability Index	0.439**	0.171	-0.136	-0.100
Pillow under the feet and eyes close				
Fourier Index 56	0.407**	0.115	-0.110	-0.081
Stability Index	0.355*	0.149	-0.096	-0.083
Head turned to the right and eyes close				
Fourier Index 56	0.318*	0.171	-0.143	-0.059
Stability Index	0.342*	0.176	-0.167	-0.078
Head turned to the left and eyes close				
Fourier Index 56	0.350*	0.257*	-0.075	-0.001
Stability Index	0.361*	0.245*	-0.097	-0.023
Head turned to the upside and eyes close				
Fourier Index 56	0.286*	0.176	-0.061	-0.095
Stability Index	0.370**	0.245*	-0.074	-0.105
Head turned to the downside and eyes close				
Fourier Index 56	0.361*	0.252*	-0.199	-0.980
Stability Index	0.374**	0.248*	-0.201	-0.100

SD: Standard deviation; CSI: Chippaux-Smirak Index; FPA: Foot position angle; * p<0.05; ** p<0.001.

Table 4. Categorical regression analyses with Fall Index as a dependent variable and Q angle, Arch Index, Chippaux-Smirak Index, and foot position angle as independent variables

	Fall index				
	Standardized coefficients				
Variable	Beta	Standard Error	F	*p*	R^2
Q angle	0.377	0.106	12.761	0.001**	
Arch Index	-0.324	0.089	13.126	0.001**	0.40
Chippaux-Smirak Index	0.161	0.088	3.380	0.070	
Foot position angle	-0.208	0.090	5.409	0.023*	

* p<0.05; ** p<0.001.

significant differences between the two sexes in terms of the Fall Index, Q angle, CSI, Arch Index, and FPA (p>0.05). Malalingments were as follows: genu varum (n=26), genu valgum (n=6), pes cavus (n=16), pes planus (n=2), and out-toeing (n=10).

In addition, we analyzed the correlation between the Q angle, CSI, Arch Index, and FPA with the Fall Index, eight-position F56, and Stability Index (Table 3). There was a moderate positive correlation between the Fall Index and the Q angle, while a weak positive correlation was found with the CSI and a weak negative correlation was found with the Arch Index and FPA. Although no correlation of the Q angle with the eyes-open F56 and Stability Index was found, a weak-to-moderate positive correlation was found with these values in the remaining seven positions. There was also a weak positive correlation between the CSI and the F56 and Stability Index in positions where the head turned to the left (HL) and downside (HF). In the position that the head turned to the upside (HB), the CSI was weakly and positively correlated only with the Stability Index. However, no correlation of the Arch

Table 5. Categorical regression analyses with the eyes-closed Fourier Index 56 as a dependent variable and Q angle, Arch Index, Chippaux-Smirak Index, and foot position angle as independent variables. In other regression models with pillow under the feet and eyes-closed Fourier Index 56, head turned to the right and eyes-closed Fourier Index 56, and head turned to the left and eyes-closed Fourier Index 56 as dependent variables and Q angle, Arch Index, and Chippaux-Smirak Index independent variables

	Eyes close - F56				
	Standardized coefficients				
Variable	Beta	Standard Error	F	*p*	R^2
Q angle	0.453	0.106	18.185	<.001**	
Arch Index	-0.159	0.098	2.626	0.110	0. 260
Chippaux-Smirak Index	0.027	0.102	0.070	0.792	
Foot position angle	-0.079	0.095	0.685	0.411	
	Pillow under the feet and eyes close-F56				
Q angle	0.294	0.145	4.096	0.047*	
Arch Index	-0.007	0.101	0.004	0.947	0.107
Chippaux-Smirak Index	0.023	0.112	0.044	0.835	
Foot position angle	-0.047	0.095	0.243	0.623	
	Head turned to the right and eyes close-F56				
Q angle	0.297	0.135	4.857	0.031*	
Arch Index	-0.030	0.103	0.088	0.768	0.106
Chippaux-Smirak Index	0.297	0.109	0.067	0.797	
Foot position angle	-0.019	0.096	0.038	0.847	
	Head turned to the left and eyes close-F56				
Q angle	0.210	0.139	2.273	0.136	
Arch Index	-0.022	0.118	0.033	0.856	0.138
Chippaux-Smirak Index	0.228	0.104	4.840	0.033*	
Foot position angle	-0.101	0.109	0.853	0.136	

* p<0.05; ** p<0.001.

Index and FPA with the F56 and Stability Index at any positions was found.

Furthermore, the categorical regression models were constructed to evaluate the factors which would affect the Fall Index, F56, and Stability Index. In the first model, the Fall Index was dependent variable, whereas the Q angle, CSI, Arch Index, and FPA were independent variables. The Q angle, Arch Index, and FPA were explained 40% of the variance of the Fall Index (p=0.001). The Q angle (Beta: 0.377, p=0.001), Arch Index (Beta: -0.324, p=0.001), and FPA (Beta: -0.208, p=0.023) were independently associated with the Fall Index. These results were demonstrated in Table 4.

In the other regression models, the dependent variables were F56 at eight positions as shown in Table 1 and the Q angle, Arch Index, and FPA were found to be independent variables. In the models that F56 in eyes-closed, pillow under the feet with eyes-closed positions, and HL were found to be dependent variables, whereas the Q angle, CSI, Arch Index, and FPA were independent variables (p<0.05). These results are shown in Table 5. We also found that the Q angle and, to a lesser degree, SCI affected the change in the F56. However, the Arch Index and FPA did not affect F56 significantly.

In final regression models, the Stability Index scores at eight different positions were separately dependent-variable and the Q angle, CSI, Arch Index, and FPA were independent variables. In five of these eight regression models, the p value was <0.05 (Table 6). We found that the Q angle was the most effective variable in the Stability Index, while the effects of CSI and Arch Index were found to be minimal.

Table 6. Categorical regression analyses with the eyes open-Stability Index as dependent variable and Q angle, Arch Index, Chippaux-Smirak Index and foot position angle as independent variables. In other regression models with eyes close-Stability Index pillow under the feet and eyes open-Stability Index, head turned to the upside and eyes close-Stability Index and head turned to the downside and eyes close-Stability Index as dependent variables and Q angle, Arch Index, Chippaux-Smirak Index and as independent variables

	Eyes open-Stability Index				
	Standardized coefficients				
Variable	Beta	Standard Error	F	*p*	R^2
Q angle	0.180	0.120	2.235	0.139	
Arch Index	-0.295	0.082	12.926	0.001**	0.158
Chippaux-Smirak Index	0.084	0.112	0.562	0.456	
Foot position angle	-0.079	0.093	0.723	0.398	
Eyes close-Stability Index					
Q angle	0.414	0.104	15.843	<0.001**	
Arch Index	-0.189	0.098	3.694	0.059	0.279
Chippaux-Smirak Index	0.113	0.097	1.362	0.247	
Foot position angle	-0.092	0.090	1.035	0.313	
Pillow under the feet and eyes open-Stability Index					
Q angle	0.415	0.122	11.468	0.001**	
Arch Index	-0.027	0.107	0.062	0.805	0.223
Chippaux-Smirak Index	0.105	0.111	0.893	0.348	
Foot position angle	-0.071	0.089	0.628	0.431	
Head turned to the upside and eyes close-Stability Index					
Q angle	0.271	0.134	4.112	0.046*	
Arch Index	-0.056	0.111	0.252	0.617	0.142
Chippaux-Smirak Index	0.167	0.104	2.572	0.113	
Foot position angle	-0.073	0.105	0.488	0.431	
Head turned to the downside and eyes close-Stability Index					
Q angle	0.231	0.140	2.714	0.104	
Arch Index	-0.082	0.104	0.620	0.434	0.177
Chippaux-Smirak Index	0.264	0.108	5.950	0.017*	
Foot position angle	-0.004	0.104	0.002	0.968	

* p<0.05; ** p<0.001.

DISCUSSION

Balance is of utmost importance in maintaining postural stability. Balance disorders with impaired motor skills lead to performance loss and an increased risk of falling.[25] The maintenance of balance depends on several factors including the vestibular system, age, pain, vision, body shape, visual-spatial perception, tactile input, agility, proprioception, and musculoskeletal and neuromuscular systems.[26] Any defect in this complex may result in imbalance and increase the risk of falling.[25] It has been shown that the risk of falling increases with increased falling-related risk factors.[8] In our study, we found a positive correlation between the Fall Index and the Q angle and CSI, and a negative correlation between the Arch Index and FPA. We also showed that the Q angle, Arch Index, and FPA had a statistically significant effect of 40% in the Fall Index. Although the effects of the lower extremity alignment parameters on the risk of falling were not seem to statistically significant, we believe that this effect may be important, considering that falling is multifactorial.

The Q angle is an important indicator of lower extremity alignment disorder.[26] Numerous studies have shown that an increase in the Q angle causes patellofemoral pain syndrome and, in this syndrome, pain leads to impaired postural control.[27-29] In a study by Potter et al.,[30] it was shown that the postural control was impaired in the flexion contracture, while Mahar et al.[31] reported that the postural control was impaired in the presence of the length difference of the lower limbs. However, the effect of the Q angle on the fall risk in healthy individuals has not been investigated, yet. In our study, we found that the increase in the Q angle also caused an increase in the risk of falling. In addition, we observed that it was the most important factor affecting the risk of falling among the evaluated parameters.

In the joint biomechanics, repetitive proprioceptive inputs constitute the basis of the somatosensory system. The F56 is an indicator of somatosensory disorder; therefore, it provides information about proprioception.[32] Proprioception plays a key role in the establishment and maintenance of the joint stability. As a result, neuromuscular control is impaired, reflex muscular activities cannot be performed, and the fall risk increases in impaired proprioception.[33] In our study, we found that, in most of the positions, the Q angle was correlated with the F56 and was the most effective parameter on F56. We considered that one of the reasons of an increased fall risk related to the Q angle, as in our study, may be a proprioceptive disorder related to its effect on the F56. However, since its impact on the F56 is not very strong, it is not possible to explain this situation with proprioception alone. The Q angle is an indicator of the strength of the quadriceps muscle and an increase in this angle reduces the mechanical effect of the power created by the quadriceps femoris.[34] It has been shown that this increase may also affect the neuromuscular response and the quadriceps reflex response time.[34,35] While postural control is achieved, peripheral inputs are united in the central nervous system, and numerous appropriate muscular responses are created. The inability of the increase in the Q angle to generate adequate muscular responses by affecting the quadriceps power may be another reason for its effect on the stability index and, hence, on the risk of falls. In previous studies, quadriceps strengthening exercises have been shown to have a positive effect on balance.[36,37] Therefore, the fall risk can be reduced by rehabilitation programs directed at the correction of the Q angle.

The foot is the structure contacting directly with the supporting surface and, thus, it plays a major role in all weight-bearing activities and balance control.[1] The Arch Index, CSI, and FPA are common tools to evaluate the lower extremity alignment. In our study, we found a negative correlation between the Arch Index and FPA with the Fall Index, while there was a positive correlation with the CSI. The reduction in the Arch Index is a sign of pes cavus, indicating that the contact between the foot and the surface is less.[38] Hertel et al.[3] reported that the postural control was impaired in cavus feet, as in our study. Maki et al.[39] showed that, as the foot contact surface decreased, less afferent stimuli were transmitted from the cutaneous receptors. It was also suggested that this reduction in sensory input might lead to the impairment of the maintenance of postural control. However, no relationship was found between the Arch Index and F56, which is an indicator of somatosensory disorders, in our study. This shows that the increase in the risk of falling due to pes cavus is not related to the impairment of the stimulus induced by the cutaneous receptors. In our study, we also found no correlation between the Arch Index and Stability Index, although there was a minimal effect on the Stability Index in only one of eight positions. These findings are similar to the results of Karthikeyan et al.[1] In pes cavus, pronation becomes restricted due to the hypomobility in the subtalar and midtarsal joints, and the center of gravity of the body shifts medially.[3,39] As a result, this hypomobility along with the reduced arch angle may be a cause of the increased fall risk.

The CSI is one of the parameters used in the evaluation of the foot medial longitudinal arch (MLA) height and the increase in this index is an indicator of the pronation of the foot.[3] Cob and Hertel[3,40] reported that COP excursions increased in the prone feet and, consequently, achieving the stability becomes more difficult. The presence of an association between the foot MLA height and lower extremity injuries has been shown in numerous studies.[16,17,35] The pronation of the foot is characterized with hypermobility of the midfoot and it is thought that hypermobile joint may lead to neuromuscular problems in maintaining balance.[41,42] In our study, although the CSI was weakly correlated with the Fall Index, we found no significant effect on the Fall Index and most of the other oscillatory parameters. We believe that this might be due to the small sample size in our study.

The foot progression angle is affected by femoral anteversion and tibiofemoral torsion, and it is an indicator of the rotational malalignment of the lower extremity.[12,13,43] In previous studies, it was shown that changes in the foot progression angle resulted in various muscular and skeletal problems; however, its effect on the risk of falling has not been investigated, yet.[44-46] In our study, according to the effects of the FPA on the Fall Index, F56 and Stability Index, we found that it only showed effects on the Fall Index. This suggests that the effect of FPA on the Fall Risk cannot be explained by proprioception. However, further studies are needed to explain the mechanism of this effect.

To the best of our knowledge, there is no study in the literature investigating the effect of lower extremity alignment on the risk of falling in healthy individuals, and this is the first study on this issue. However, further, large-scale studies evaluating other lower extremity alignment factors are required to confirm these findings.

In conclusion, we found that lower extremity malalignment increases the risk of falling. We believe that the risk of falling can be decreased by reducing these malalingments and, thus, fall-related mortality and morbidity can be further reduced. In addition, the correction of the lower extremity malalignment by exercises or orthesis would also reduce the fall risk.

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