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Original Article

Toe functions have little effect on dynamic balance ability in elderly people

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Abstract. [Purpose] The purpose of this study was to examine the toe function of elderly people and the association with the dynamic balance ability for the developing effective fall-prevention measures. [Subjects and Methods] Seventy-eight participants in a community health service were included in this cross-sectional study. The Timed Up and Go Test and Four Square Step Test were used to test dynamic balance ability. The toe functions related to dynamic balance ability were toe flexion strength, presence or absence of restricted range of motion of the hallux, presence or absence of hallux pain, and hallux valgus angle. [Results] Factors related to the Timed Up and Go Test results were toe flexion strength, age, and presence or absence of hallux pain. Their standard partial regression coefficients were −0.400, 0.277, and −0.218, respectively. Factors related to the Four Square Step Test results were toe flexion strength and age. Their standard partial regression coefficients were −0.334 and 0.277, respectively. [Conclusion] Toe functions appear to have little impact on dynamic balance ability in elderly people who have mild toe dysfunction. Approaches that address not only the toes, but trunk functions, and other leg joints should be investigated for improving the dynamic balance ability.

Key words: Elderly, Dynamic balance ability, Toe function

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INTRODUCTION

Reduced dynamic balance ability is a major risk factor for falls among community-dwelling elderly people. Past studies that examined fall-related factors in elderly people observed correlations with falls using the Timed Up and Go Test (TUGT), and the Four Square Step Test (FSST), all of which test dynamic balance ability[1–3]. Falls in elderly people are most often caused by changes in the support surface and shifts of the physical center of gravity during walking. It thus makes sense that reduced dynamic balance ability would correlate with falls. Maintaining and increasing dynamic balance ability are important factors in fall prevention. Toe function is one factor that relates to dynamic balance ability. Toe dysfunction in elderly people can lead to reduced dynamic balance ability, such as through reduced toe strength, reduced range of motion (ROM), pain, and deformation. In previous studies that examined the correlation between dynamic balance ability and toe functions in elderly people, reduced toe flexion strength was found to correlate with reduced dynamic balance ability[4)]. However, there are few reports that examined a dynamic balance and the association with the toe functions. Determining the extent to which toe functions can reduce dynamic balance ability in elderly people would likely help in creating effective fall-prevention measures. The objective of this study was to determine the extent to which toe functions affect dynamic balance ability in elderly people. In addition to toe flexion strength, we focused on hallux ROM, hallux pain, and hallux valgus deformation.

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SUBJECTS AND METHODS

The participants were 106 ambulant elderly people who were participating in a community health service in September 2014. The exclusion criteria were data defective person and male. After excluding 28 people who fell under the exclusion criteria, there were 78 participants (mean and standard deviation, age 84.8 ± 4.4 years, weight 46.3 ± 7.0 kg, height 143.4 ± 5.7 cm). Subjects were included after obtaining informed consent, and the study protocol was approved by the Ethics Committee of Seirei Christopher University (approval number 15092).

This study used a cross-sectional design. The TUGT and the FSST were used to test dynamic balance ability. The toe functions thought to be related to dynamic balance ability were toe flexion strength, presence or absence of restricted hallux ROM, presence or absence of hallux pain, and hallux valgus angle. The items surveyed for this study were measured in yearly health checks. Researchers practiced measuring all the evaluation items before executing the measurements in the study. The data used in the study was from past measurements that were stored on a personal computer belonging to the principal investigator's institution. The principal investigator extracted the data from this computer.

Participants began the TUGT sitting on the edge of a chair with armrests[5]. The test measures the time it takes a participant to stand up from the chair, walk to a mark 3 m away, walk back to the chair, and sit back down. A researcher instructs the participant to walk as fast as possible without falling. Repeat measurements were taken if there were major divergences in the measurements, or if the participant needed assistance to keep from falling. Two measurements were taken after one practice test, and the mean value of the two measurements was recorded.

In the FSST, four sticks are laid out in a cross to create four quadrants[3]. The participant made two trips around the quadrants, stepping over the sticks as quickly as possible going forward, backward, left, and right. The participant began in a standing position in the left-front quadrant, moves clockwise once around the quadrants, then makes a counterclockwise circuit of the quadrants. The time it takes the participant to make one round trip was measured with a stopwatch. During the test, the participant must stop with both feet together in each quadrant, being careful not to touch the sticks when walking over them. If the participant touches a stick or loses her balance and needs the assistance of a researcher, the test is repeated. Two measurements were taken after one practice test, and the mean value of those was recorded.

Toe flexion strength was measured with a toe grip strength measurement device (TKK3361, Takei Scientific Instruments Co.)[6]. Measurements were performed with the participant sitting on the edge of a chair with the hip and knee joints flexed to 90°. A researcher held the participant's heel stable during the measurement. Toes on the pivot foot were measured. Two measurements were taken after one practice test, and the mean value of the two measurements divided by body weight was recorded. Hallux ROM was measured by passively moving the metatarsophalangeal joint of the hallux. The total ROM for flexion and extension was calculated[7]. Metatarsophalangeal joint ROM was measured with a goniometer, with the first metatarsal as the base axis and the first phalange as the moving axis. Restricted metatarsophalangeal ROM was defined as less than 75° ROM, while 75° or greater was considered unrestricted. Presence or absence of hallux pain was determined by asking the participants whether they experienced pain in the hallux during regular walking. Absence of hallux pain was defined as having absolutely no pain during walking, while presence of pain was when even mild pain was experienced. The hallux valgus angle was measured as the angle formed by the lines tangent to the proximal medial portion and the distal medial portion of the first metatarsophalangeal joint on a footprint (Bauerfeind). Footprints were taken by having the participants place their feet on the footprint while in a sitting position, then standing up.

Age, knee extension strength, extremity skeletal muscle mass, and cognitive functions were considered confounding factors related to dynamic balance ability. Knee extension strength was measured using a hand held dynamometer (ANIMA Co.)[8]. Measurements were performed with the participant sitting in a chair and the lower legs hanging down. A sensor pad was attached to the distal lower leg. The distal lower leg was then attached to a posterior support with a belt so the lower leg hung straight down. Measurements were performed on the pivot foot. The participants performed isometric knee extensions at maximum exertion for about 3 s, and the maximum value during this time was recorded. Three measurements were taken, with at least 30 s between them. The mean of the three measurements divided by body weight was recorded. Extremity skeletal muscle mass was measured using an 8-point contact electrical impedance tomograph (Kobe Medi-care Co. Ltd). Measurements of skeletal muscle mass were divided by the square of the participant's height (m^2) to obtain the skeletal muscle mass index (SMI) (kg/m^2). Cognitive functions were evaluated using the Japanese version of the Montreal Cognitive Assessment (MoCA-J)[9].

Correlations between dynamic balance ability and toe functions were examined by calculating the correlation coefficients of the TUGT and FSST results with toe flexion strength, presence or absence of restricted hallux ROM, presence or absence of hallux pain, hallux valgus angle, age, knee extension strength, and extremity skeletal muscle mass using Pearson product moment analysis and Spearman rank correlation analysis. Next, multiple regression analyses were performed with the TUGT and FSST results as the objective variables, and toe flexion strength, presence or absence of restricted hallux ROM, presence or absence of hallux pain, and hallux valgus angle as the explanatory variables. The analyses were adjusted for age, knee extension strength, and extremity skeletal muscle mass. In the multiple regression analyses, the influence of multicollinearity was examined beforehand, and it was confirmed that the correlation coefficients from a correlation matrix of the explanatory variables were $r>0.90$ or $r<-0.90$, or that there were no variance inflation factors of 10 or higher. The step-wise method of

Table 1. Characteristics of the participants

Variable	Median	Interquartile range
Age (years)	86	82–88
Body Mass Index (kg/m^2)	22.1	19.7–25.0
Timed Up and Go test (seconds)	9.6	8.2–11.2
Four Square Step Test (seconds)	9.9	8.4–12.3
Knee extension strength (kgf / kg)	0.24	0.20–0.34
Skeletal Muscle Mass Index (kg/m^2)	6.8	6.5–7.7
Japanese version of Montreal Cognitive Assessment (point)	21	18–24
Toe flexion strength (kg)	4.7	3.2–6.9
Hallux valgus angle (deg)	11	7–18

Table 2. Coefficient of correlation of the dynamic balance and explanation variable

Variable	Timed Up and Go test	Four Square Step Test
Age	0.410**	0.382**
Knee extension strength	−0.355**	−0.311**
Skeletal Muscle Mass Index	0.171	0.172
Japanese version of Montreal Cognitive Assessment	−0.345**	−0.329**
Toe flexion strength	−0.507**	−0.443**
Presence or absence of restricted range of motion of the hallux	−0.160	−0.022
Presence or absence of hallux pain	−0.191	−0.169
Hallux valgus angle	0.110	0.147

**p<0.01
Real number: Age, Knee extension strength, Skeletal Muscle Mass Index, Montreal Cognitive Assessment, Toe flexion strength, Hallux valgus angle
Dummy variable: Presence or absence of restricted range of motion of the hallux (0: presence, 1: absence)
Presence or absence of hallux pain (0: presence, 1: absence)

multiple regression analysis was used. SPSS version22 was used for statistical analysis (IBM Co.). The significance level was 5 percent.

RESULTS

Table 1 shows the participants' characteristics. Their median (interquartile range) age was 86 years (82–88) and the TUGT result was 9.6 s (8.2–11.2), indicating that while this was an elderly population, it had good dynamic balance ability. For toe functions, the hallux valgus angle was 11° (7–18), with few participants having angles of 20° or greater, and 7.7 percent of participants experienced hallux pain while walking, which indicated that toe dysfunction was mild in this population. 12.8 percent of participants had limitation of hallux of ROM.

The correlation analyses showed that the TUGT results were significantly correlated with age, knee extension strength, MoCA-J score, and toe flexion strength, with correlation coefficients of 0.410, −0.355, −0.345, and −0.507, respectively (Table 2). For the FSST results, significant correlations were observed with age, knee extension strength, MoCA-J score, and toe flexion strength, with correlation coefficients of 0.382, −0.311, −0.329, and −0.443, respectively.

The multiple regression analysis extracted toe flexion strength, age, and presence or absence of hallux pain as factors related to the TUGT results. The standard partial regression coefficients of the final model were −0.400, 0.277, and −0.218, respectively (Table 3). The model combinations were toe flexion strength for model 1, toe flexion strength and age for model 2, and toe flexion strength, age, and presence of hallux pain for model 3. Their coefficients of determination adjusted for degrees of freedom were 0.204, 0.275, and 0.315, respectively. Toe flexion strength and age were factors extracted as related to the FSST results. The standard partial regression coefficients of the final model were −0.334 and 0.277, respectively (Table 4). The model combinations were toe flexion strength for model 1, and toe flexion strength and age for model 2. Their coefficients of determination adjusted for degrees of freedom were 0.145 and 0.208, respectively.

Table 3. Results of multiple regression analysis for the dependent variable Timed Up and Go test

Model	Variable	β	p value	Coefficient of determination adjusted for degrees of freedom
1	Toe flexion strength	−0.463	0.001	0.204
2	Toe flexion strength	−0.399	0.001	0.275
	Age	0.289	0.005	
3	Toe flexion strength	−0.400	0.001	0.315
	Age	0.277	0.005	
	Presence or absence of hallux pain	−0.218	0.024	

Dependent variable: Timed Up and Go test
Independent variables: Age, Knee extension strength, Skeletal Muscle Mass Index, Montreal Cognitive Assessment (0: 25 under, 1: 26 over), Toe flexion strength, Presence or absence of restricted range of motion of the hallux (0: presence, 1: absence), Presence or absence of hallux pain (0: presence, 1: absence), Hallux valgus angle

Table 4. Results of multiple regression analysis for the dependent variable Four Square Step Test

Model	Variable	β	p value	Coefficient of determination adjusted for degrees of freedom
1	Toe flexion strength	−0.394	0.001	0.145
2	Toe flexion strength	−0.334	0.002	0.208
	Age	0.277	0.010	

Dependent variable: Four Square Step Test
Independent variables: Age, Knee extension strength, Skeletal Muscle Mass Index, Montreal Cognitive Assessment (0: 25 under, 1: 26 over), Toe flexion strength, Presence or absence of restricted range of motion of the hallux (0: presence, 1: absence), Presence or absence of hallux pain (0: presence, 1: absence), Hallux valgus angle

DISCUSSION

First, the toe flexion strength of community-dwelling elderly people was found to be independently related to dynamic balance ability, even following adjustments for age. The dynamic balance ability of elderly people is known to decline along with age. Moreover, factors such as spinal kyphosis and flexion contracture of the hip and knee joints can cause the physical center of gravity to shift posteriorly, reducing usage of the forefoot and causing toe flexion strength to decline. In a previous study that examined the relationship between dynamic balance ability and toe flexion strength in community-dwelling elderly people, reduced dynamic balance ability was associated with lower toe flexion strength, which supports the findings of our study[4]. In a study of an approach that addressed toe functions to prevent falls in elderly people, increased toe strength was associated with increased dynamic balance ability. Our findings, which show a correlation between toe flexion strength and dynamic balance ability, provide further evidence to suggest that toe interventions could contribute to improving dynamic balance.

Second, while toe flexion strength and hallux pain were related to the TUGT results among community-dwelling elderly people, the impact of toe functions on dynamic balance ability was small. In a previous study that examined how falls correlate with toe functions and foot functions among elderly people, falls were associated with hallux valgus and severe foot pain[10]. However, the influence of toe functions on the TUGT and FSST results in the present study went from approximately 15 to 25 percent following adjusting for age, suggesting toe functions have little impact on dynamic balance ability. Most of the participants in the present study did not experience pain while walking, few had severe hallux valgus, and few had other toe problems or disease. A study that examined the correlations of falls with common foot problems, such as skin inflammation and ingrown nails, found no direct correlation between foot problems and fall incidence, which is along the same lines as our findings[11]. The correlation between toe functions and dynamic balance ability in community-dwelling elderly people suggests that improving toe functions could help increase dynamic balance ability. However, the effect of interventions that only address toe functions would likely be limited for elderly people with mild toe dysfunction. Approaches that address not only the toes, but trunk functions, the ankles, hips, and other leg joints should be investigated for improving the dynamic balance ability of elderly people.

First limitation, the participants of this study were elderly people who were voluntarily participating in a community health service, meaning they had high awareness of their own well-being. Elderly participants who participate in a community health service often have high levels of physical functions; hence, care should be taken when generalizing these results.

Second limitation, the items used to evaluate the toe functions that relate to dynamic balance were insufficient. Our examination of the correlation between dynamic balance ability and toe functions mainly focused on hallux functions, and did not consider the impact of factors such as mobility or deformation of the second to fifth toes. This is a topic for future research.

In this study, we examined correlations between toe functions and dynamic balance ability in community-dwelling elderly people. The results showed that toe flexion strength and hallux pain correlated with TUGT results, and toe flexion strength correlated with FSST results, though for both, the impact on dynamic balance ability was small. While improving toe functions could help improved dynamic balance ability among community-dwelling elderly people, the therapeutic effect of interventions that only address toe functions would likely be limited for elderly people with mild toe dysfunction.

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