Relationship between characteristics of plantar pressure distribution while standing and falls in community-dwelling elderly

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Relationship between characteristics of plantar pressure distribution while standing and falls in community-dwelling elderly

Tomoko Hiramatsu, Kiyoko Izumi*

Abstract

【Objectives】: The purpose of this study was to clarify the characteristics of plantar pressure distribution while the community-dwelling elderly were standing, and to investigate the relationship between plantar pressure distribution and falls.

【Methods】: Subjects comprised 87 community-dwelling elderly individuals (14 men, 73 women; mean age, 75.0 ± 6.4 years) who were independent in activities of daily living. Data were obtained over time using a plantar pressure measuring system. The foot arch area was divided into 5 sections (divided into forefoot, midfoot, and heel) and the toe area was divided into 5 sections (each toe). Plantar pressure was then quantitatively calculated in center of foot pressure (CFP) position of 45%FL (relative distance from the heel with respect to foot length), 50%FL, 55%FL amd 60%FL. CFP position was based on the findings of preceding studies. CFP position of 45%FL was the highly stable quiet stance position. And CFP position of 60%FL was the forward limit of a quiet stance. Load values for the 10 areas are shown as relative values (%) with respect to the full load on the plantar portion of one foot. The loads on the 10 parts of each foot were calculated based on the CFP position, and similarities and differences between them were examined to identify any variation in the toe pressure. So toe pressur of 45%FL and 60 %FL was classified.

【Results】: **1.** Plantar pressure distribution was classified into 3 pattern. Group 1: toe pressure was lower than the mean value of the toe puressures at 45%FL and higher than the mean value of the toe puressures at 60%FL. Group 2: toe pressure was higher than the mean value of the toe puressures at 45%FL and higher than the mean value of the toe puressures at 60%FL. Group 3: toe pressure was lower than the mean value of the toe puressures at 45%FL and lower than the mean value of the toe puressures at 60%FL. **2.** It related to the 3 pattern of plantar pressure distribution and walking time, the history of falls. And there were a lot of occurrences of the falls in Group 3. The highest relativ risk of falls was Group 3 (RR : 4.0).

【Conclusion】: To prevent falls in the elderly, we focused on stability in standing posture and quantitatively investigated plantar pressure distribution. Characteristics of toe pressure showed 3 patterns related to falls. This suggests that plantar pressure distribution in a standing posture may be one indicator for predicting falls may be effective in preventing falls.

Key words

elderly, community-dwelling, prevention of falls, standing, plantar pressure distribution

Division of Health Sciences Kanazawa University Graduate School of Medical Science (School of Heahth Sciences, College of Medical, Pharamaceutical and Health Sciences, Kanazawa University)

* School of Heahth Sciences, College of Medical, Pharamaceutical and Health Sciences, Kanazawa University

Introduction

The elderly are susceptible to falls, and effects of falls have been shown to include trauma and fear of falling, which can lead to a restricted range of activities of daily living. In about 10% of people who require care, a fall was the event that precipitated this state[1]. Then, Prevention of falls is thus extremely important in maintaining quality of life in community-dwelling elderly.

A characteristic of falls in the elderly is that they occur from loss of balance, particularly when no external force is present, while the individual is performing activities of daily living. Intervention to improve stability in a standing posture is thus thought to be one effective way to prevent falls. Stability of standing posture is the ability to maintain the body's center of gravity within the base of support. The present study focused on the feet, since the feet are used to correct small losses of balance.

With regard to the feet and falls in the elderly, decreased strength in the toe flexor muscles is reportedly related to falls and to walking ability and balance, which are factors in falls[2·3]. Using footprints, we analyzed plantar images of elderly people and reported a relationship between the status of ground contact of the toes and experience of falls[4·5].

The foot region can structurally be divided into the foot arch area and toes, and functions to support the standing posture. The foot arch area forms a firm unit consisting of three arches, whereas the toes abound in mobility. When standing still, the center of foot pressure position (hereafter, CFP position; i.e., the center of gravity of the body projected onto the foot region) in the anteroposterior direction is approximately 30–60% from the heel relative to the foot length (hereafter %FL)[6] ; the average value is about 45%FL[7-10]. In this position, most plantar pressure is evenly distributed between the forepart of the foot and heel[11-14]; the peak value for the former occurs at either the second or third metatarsal head[14-17]. However, the peak value differs when the foot region is deformed[14]. In addition, pressure increases in the forepart of the foot during anteversion and in the heel part during retroversion[6]. This suggests that stabilization of the standing posture is achieved by making the plantar pressure distribution fluctuate as a result of the morphology of the foot arch area and CFP position.

Although there are few reports on toes, there is a report claiming that whereas toe pressure is about 3% of body weight during quiet standing, activity of the abductor pollicis muscle and toe pressure rapidly increases when the CFP moves beyond 60%FL in the anterior direction[6]. The abductor pollicis muscle is one of the flexor pollicis groups of muscles; its assumed function is to maintain an arch structure in response to increased load upon the foot arch region that accompanies anteversion. At the same time, it is speculated that flexors of other toes also become involved.

These observations suggest that the functions of the foot arch and toes differ depending on the CFP position, that posture is maintained while standing still by supporting body weight with the foot arch region, and that the foot arch and toes support body weight and maintain posture in association with forward movement of the CFP position. However, subjects in previous studies were adults, and the actual state in the elderly has not been clarified. In addition, when carrying out activities of daily living, it is necessary to maintain a variety of different positions within the base of support, depending on the circumstances. Standing still while reaching forward is one of the basic movements; it is likely that postural adjustment by toe pressure is important, although investigations for each toe have not been conducted.

The purpose of this study was to clarify the characteristics of plantar pressure distribution while the community-dwelling elderly were standing, and to investigate the relationship between plantar pressure distribution and falls.

Methods

1. Study subjects

Subjects comprised 87 people ≥65 years old (14 men, 73 women; mean age, 75.0 ± 6.4 years) who underwent physical fitness measurements in 2005. All subjects were participants in a health class

who lived in the community and were independent in terms of activities of daily living. None of the subjects showed visual and/or auditory impairment interfering with activities of daily living. They were all capable of walking outdoors. Their ankle and toe mobility and plantar sensation were normal. There was no person with hemiplegia.

Physical fitness measurements including a questionnaire survey on health were incorporated into the health class program.

2. Data collection

From the results of the 2005 physical fitness measurements and questionnaire survey completed by the subjects, information was gathered on plantar pressure, balance, muscle strength, and walking ability, which are considered to be key factors in falls, and on falls themselves. Information on sex, age, height, weight, and foot length was also collected as basic data. Data were gathered again in 2007 to follow changes in plantar pressure. To understand the status of falls in 2005, information on experience of falls was collected in 2006.

1) Measurement position and methods in physical fitness measurements

(1) Plantar pressure: Measurements were made using a plantar pressure measurement system that consists of a plate-like measuring device and an analyzer (RS Scan International, Belgium). The plate portion is fitted with pressure sensors at 5×7mm intervals, with each sensor able to detect loads ≥0.3 N. The measurement is shown in colour imaging and load value (Newton) through the analyzer. The measurement posture was adopted with reference to a cross test [18]. After standing in a quiet stance for 30 s, subjects slowly flexed their ankles and leaned forward in manner comfortable to them, maintaining their forwardmost leaning position for 3 sec. Subjects practiced this movement before measurements were made.

(2) Balance, muscle strength, walking ability: Static balance was measured using movement of the center of gravity with eyes open and closed[19], and dynamic balance was measured with the functional reach test[20]. Grip strength was measured using a grip dynamometer, and toe flexor force was measured using a toe checker[21]. For walking ability, 10-m walking speed and number of steps with normal walking and a step test were measured with reference to items in walking software that measures movement ability[22]. The reliability and validity of all methods has been demonstrated.

2) Questionnaire survey

Experience of falls and fear of falling were examined in a group survey using a self-completed survey form.

3. Data analysis

1) Calculation of CFP position

CFP position was calculated from the pressure center point in the forward-backward direction

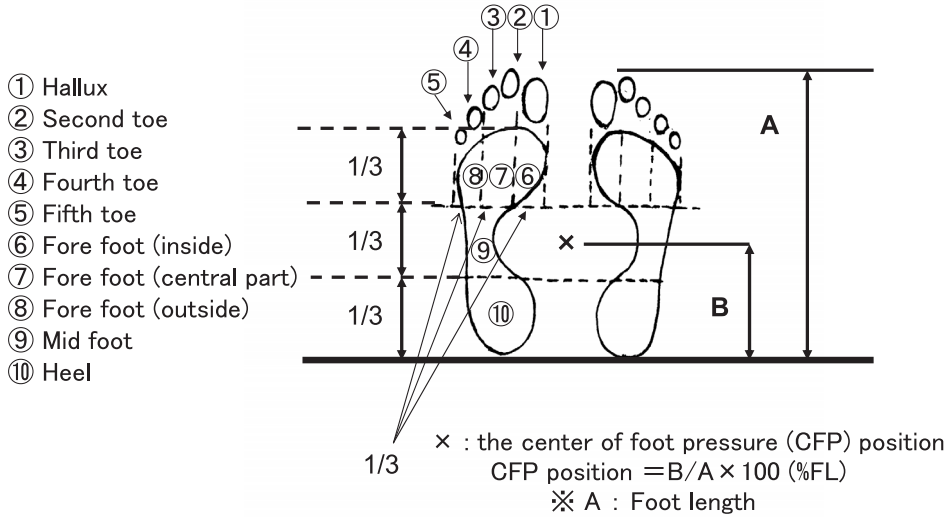

Figure 1. 10 areas in plantar and CFP position

obtained with the RS Scan and foot length, and shown as relative distance (% foot length) from the heel with respect to foot length.

2) Plantar distribution and display of Plantar pressure

The foot was divided into the following 10 areas based on morphological characteristics. The toes were divided into 5 sections, one for each toe. The foot arch was divided into 3 equal sections from the heel to the tip of the arch in the longitudinal direction: the heel; midfoot; and forefoot. The forefoot was then divided equally along the width of the foot into the inside forefoot, central forefoot, and outside forefoot. (Figure 1). Next, the left and right load values were calculated with every 1%FL increment in CFP position from a quiet stance to the forwardmost inclination. Load values for the 10 areas are shown as relative values (%) with respect to the full load on the plantar portion of one foot.

3) Feature in plantar pressure that accompanied forward movement of the CFP position

Mean plantar pressure and standard deviation were obtained from the CFP position in 45%FL, 50%FL, 55%FL and 60%FL. And relative change with respect to plantar pressure in the CFP position in 45%FL was obtained. The findings of a previous study that the average value of CFP position in a quiet stance was about 45%FL[7-10]. As for this position, the stability of the standing posture is the highest. The findings of a previous study that CFP position of 60%FL was the forward limit of a quiet stance[6].

First, the entire average of plantar pressure distribution and change ratio according to CFP position was put out.

Next, the loads on the 10 parts of each foot were calculated based on the CFP position, and similarities and differences between them were examined to identify any variation in the toe pressure. Based on the findings of preceding studies on the plantar pressure distribution in adults[6], the plantar distribution patterns were determined by calculating the mean toe pressures during the steadiest CFP position in the quiet stance and during the CFP at 60%FL, which is the maximum extent of anterior displacement, and analyzing the combinations of the values above and below the mean. And, The mean plantar pressure, standard deviation, and ratio to the plantar pressure during the quiet stance were calculated at intervals of 5% along the course of the mean CFP position while adopting a quiet stance by pattern.

Changes over time were investigated in 48 individuals who underwent measurements twice, in 2005 and 2007.

4) Relationship between plantar pressure distribution and falls

(1) Relationships between plantar pressure distribution and the key fall factors of balance, muscle strength, and walking ability, and falls themselves, were investigated.

(2) To examine the relationship between falls and the plantar pressure distribution, as well as the other factors related to falls, the relative risk was calculated. Falls was analyzed based on the results of a follow-up study conducted during the year following the measurement of the plantar pressure distribution.

4. Statistical analysis

Statistical analysis was performed using SPSS version 13.0 software (SPSS, Japan), with $p<0.05$ taken as the level of statistical significance. In two-way repeated measures analysis of variance of the plantar pressure, multiple comparisons were performed involving the left and right feet together when there was no significant interaction between them but a significant main effect in the region. The relationship between distribution patterns of plantar pressure and fall factors was investigated using a χ^2 test or one-way analysis of variance and multiple comparisons.

5. Ethical considerations

All study protocols were approved by the medical ethics committee of Kanazawa University (approval No. 251). A written explanation was given to the person in charge of the health class, and consent was obtained in writing from each subject prior to participation. The researchers did not have a correspondence table, and received the data only after anonymiszation to remove personal

information.

Results

1. Summary of CFP position and plantar pressure distribution

Mean CFP position in a quiet stance was 43.3 ± 4.7% FL.

No bilateral differences were seen in any CFP position.

Figure 2 showed the plantar pressure distribution according to CFP position. With a CFP position of 45% FL, toe pressure was 6.8% of total plantar pressure. Pressure of the forefoot and heel each accounted for about 40% of total plantar pressure. In the forefoot, pressure in the central part accounted for 50% and pressure in the inside and outside parts accounted for about 25% each.

Total toe pressure increased with forward movement of the CFP position, and differences were seen between 45%FL and 50%FL, 55%FL, 60%FL ($p<0.05$), between 50%FL and, 55%FL, 60%FL ($p<0.05$), between 55%FL and, 60%FL ($p<0.05$). Pressure was largest in the hallux, which accounted for more than 50% of toe pressure in all CFP positions. The change ratio was also largest in the hallux.

In the foot arch, no difference was seen in the forefoot and the midfoot as a result of CFP position. Peak plantar pressure of forefoot was CFP position of 55%FL, and peak plantar pressure of midfoot was CFP position of 55%FL, showing gradually unimodal distribution. Pressure on the heel decreased with forward movement of the CFP position, and a difference was seen similar to Total toe pressure.

In the 48 people who could be measured twice, no differences in plantar pressure were seen between 2005 and 2007.

2. Plantar pressure distribution patterns accompanying forward movement in CFP position

Based on the mean value of the toe pressures on adopting CFP positions at 45%FL and 60%FL, 3 patterns of plantar pressure distribution were identified. The mean value of the toe pressures on adopting CFP positions at 45%FL was 6.8% of total plantar pressure and the mean value of the toe pressures on adopting CFP positions at 60%FL was 23.7% of total plantar pressure.

Group 1: toe pressure was lower than the mean value of the toe puressures at 45%FL and higher than the mean value of the toe puressures at 60%FL. Group 2: toe pressure was higher than the mean value of the toe puressures at 45%FL and

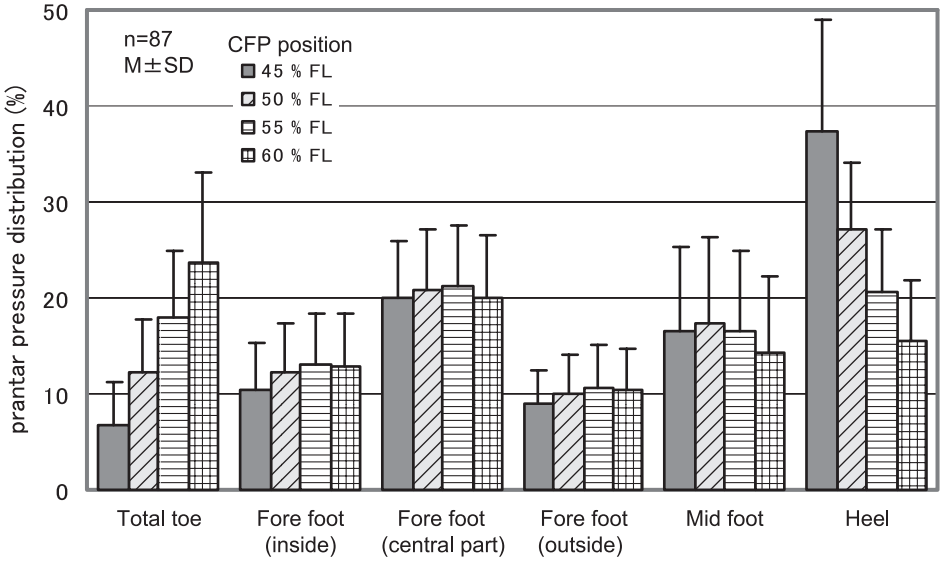

Figure 2. Plantar pressure distribution according to CFP position

Total toe, and heel forces at a CFP position of 45 % FL differ from those at CFP positions of 50, 55 and 60 % FL ($p<0.05$), CFP position of 50 % FL differ from those at 55 and 60 % FL ($p<0.05$), CFP position of 55 % FL differ from those at 60 % FL ($p<0.05$)

Table 1. Characteristics of the subjects according to three Groups

n=87

Item		Plantar pressure distribution pattern		
		Group 1 n=31	Group 2 n=18	Group 3 n=38
Gender	Male	6 (19.4%)	4 (22.2%)	3 (7.8%)
	Female	25 (80.6%)	14 (77.8%)	35 (92.2%)
Age (years)		74.6±4.7	76.4±6.4	76.7± 7.4
Height (cm)		155.2±7.2	153.9±8.1	149.3± 7.8
Weight (kg)		55.1±8.1	53.4±8.0	51.8±11.6
BMI (kg/m²)		22.8±2.8	22.6±3.1	23.1± 4.2
Foot length (cm)		23.0±1.4	22.5±1.6	22.4± 1.6
CFP position; quiet stance (% FL)[1)]		43.8±4.4	46.1±3.7	42.9± 6.5

multiple comparison (post ANOVA)
1) significant differece between Group 1 and Group 2, Group 2 and Group 3 ($p<0.05$)

higher than the mean value of the toe puressures at 60%FL. Group 3: toe pressure was lower than the mean value of the toe puressures at 45%FL and lower than the mean value of the toe puressures at 60%FL. Group 1 was 31 subjects (35.6%), Group 2 was 18 subjects (20.7%), and Group 3 was 38 subjects (43.7%).

1) Summary of subjects by group (Table 1)

No differences were seen between the 3 groups in age, sex, height, weight and BMI, or foot length. CFP in a quiet stance was furthest forward in Group 2, at 46.1 ± 3.7% FL, and 43.8 ± 4.4% FL in Group 1 and 42.9 ± 6.5% FL in Group 3. A significant difference was seen between Group 2 and Groups 1 and 3 ($p<0.05$).

2) Variation in plantar pressure in the 3 groups with forward movement of the CFP position

(1) Group 1 (Table 2)

With a CFP position of 45% FL, toe pressure was 6.2% of total plantar pressure, with hallux pressure comprising 46.8% if this. Pressure on the foot arch was about 40% of total plantar pressure in both the forefoot and heel, and 17% of total plantar pressure in the midfoot.

Toe pressure increased with forward movement of the CFP position. In the hallux through third toes, significant differences were seen between 45% FL and 50%, 55%, and 60% FL ($p<0.05$), between 50% FL and 55%, 60% FL ($p<0.05$), between 55% FL and 60% FL ($p<0.05$). In the fourth toes,

Table 2. Plantar pressure distribution and change ratio of Group 1 according to CFP position

n=62

Area	CFP position						
	45 % FL	50 % FL		55 % FL		60 % FL	
	Force[1)] (SD)	Force (SD)	Change Ratio[2)]	Force (SD)	Change Ratio	Force (SD)	Change Ratio
Total toe	6.2 (3.1)	13.5 (5.8)	2.18	20.0 (7.1)	3.23	29.9 (9.1)	4.82
Hallux[3)]	2.9 (2.1)	6.8 (3.6)	2.34	10.1 (4.7)	3.48	15.4 (5.4)	5.31
Second toe[3)]	1.0 (0.9)	2.4 (2.0)	2.40	3.5 (2.4)	3.50	5.2 (2.3)	5.20
Third toe[3)]	1.0 (0.9)	2.1 (1.3)	2.10	3.0 (1.6)	3.00	4.0 (1.9)	4.00
Fourth toe[4)]	0.9 (0.9)	1.5 (1.2)	1.67	2.2 (1.3)	2.44	3.4 (1.7)	3.78
Fifth toe	0.4 (0.4)	0.7 (0.8)	1.75	1.2 (1.0)	3.00	1.9 (1.5)	4.75
Fore foot (inside)	10.0 (5.4)	11.9 (5.5)	1.19	12.7 (5.7)	1.27	12.5 (6.5)	1.25
Fore foot (central part)	19.8 (7.6)	20.6 (7.3)	1.04	20.6 (7.3)	1.04	19.1 (6.7)	0.96
Fore foot (outside)	9.1 (4.5)	9.3 (4.2)	1.02	9.8 (4.6)	1.08	9.6 (4.7)	1.05
Mid foot	17.0 (8.5)	17.6 (9.4)	1.04	16.2 (8.8)	0.95	14.2 (8.3)	0.84
Heel[3)]	38.0 (11.8)	27.0 (5.5)	0.71	20.8 (6.6)	0.55	14.8 (7.1)	0.39

1) %
2) Change ratio refers to the ratio relative to the force at the CFP position of 45 % FL.
multiple comparison (post ANOVA)
3) CFP position of 45 % FL differ from those at 50, 55 and 60 % FL, CFP position of 50 % FL differ from those at 55 and 60 % FL, CFP position of 55 % FL differ from those at 60 % FL ($p<0.05$).
4) CFP position of 45 % FL differ from those at 55 and 60 % FL, CFP position of 60 % FL differ from those at 50 and 55 % FL ($p<0.05$).

significant differences were seen between 45% FL and 55%, 60% FL ($p<0.05$), between 60% FL and 50%, 55% FL ($p<0.05$). Pressure was largest in the hallux, which accounted for more than 50% of toe pressure in all CFP positions.

In foot arch pressure, no differences were seen in the forefoot or midfoot as a result of CFP position. Pressure on the heel decrease with forward movement of the CFP position, and a difference was seen between 45% FL and 50%, 55%, and 60% FL ($p<0.05$), between 50% FL and 55%, 60% FL ($p<0.05$), between 55% FL and 60% FL ($p<0.05$).

(2) Group 2 (Table 3)

With a CFP position of 45% FL, toe pressure was 11.7% of total plantar pressure, of which hallux pressure comprised 49.6%. Pressure on the foot arch was 40.6% of total plantar pressure in the forefoot, 31.3% of total plantar pressure in the heel, and 16.5% of total plantar pressure in the midfoot.

Toe pressure increased with forward movement of the CFP position. In the hallux, a significant difference was seen between 45% FL and 55%, 60% FL ($p<0.05$), between 50 % FL and 55%FL, 60% FL ($p<0.05$), and between 55 % FL and 60% FL ($p<0.05$). In the second through fourth toes a significant difference was seen between 45% FL and 60% FL, and between 50 % FL and 60% FL ($p<0.05$). A significant difference was seen between 45% FL and 55% FL in the hallux only, and the increase in pressure on the hallux was earlier than on the other toes. Pressure was largest on the hallux, which accounted for about 50% of toe pressure in all CFP positions.

In foot arch pressure, no differences were seen in the forefoot or midfoot as a result of CFP position. Pressure on the heel decrease with forward movement of the CFP position, and a difference was seen between 45% FL and 55% FL, 60% FL ($p<0.05$), between 50% FL and 55%, 60% FL ($p<0.05$). Pressure on the forefoot and midfoot was the same as in Group 1.

(3) Group 3 (Table 4)

With a CFP position of 45% FL, toe pressure was 5.8% of total plantar pressure, with hallux pressure comprising 51.7%. Pressure on the foot arch was about 40% of total plantar pressure in both the forefoot and heel, and 17.5% of total plantar pressure in the midfoot. Pressure on the arch was the same as in Group 1.

Toe pressure increased with forward movement of the CFP position, and differences were seen in the hallux through fourth toes between 45% FL and 55% FL, 60% FL ($p<0.05$) and between 50 % FL and 60% FL ($p<0.05$). Pressure was largest on the hallux, which accounted for about 50% of toe

Table 3. Plantar pressure distribution and change ratio of Group 2 according to CFP position

n=36

Area	CFP position							
	45 % FL	50 % FL		55 % FL		60 % FL	
	Force[1] (SD)	Force (SD)	Change Ratio[2]	Force (SD)	Change Ratio	Force (SD)	Change Ratio
Total toe	11.7 (4.1)	15.2 (4.5)	1.30	17.3 (5.3)	1.48	27.3 (8.3)	2.33
Hallux[3]	5.8 (3.6)	6.8 (2.8)	1.17	10.2 (3.8)	1.76	14.6 (6.2)	2.52
Second toe[4]	2.1 (1.3)	2.7 (1.4)	1.29	3.6 (1.9)	1.71	4.6 (2.4)	2.19
Third toe[4]	1.9 (1.1)	2.5 (1.0)	1.32	3.0 (1.3)	1.58	3.9 (1.9)	2.05
Fourth toe[4]	1.3 (1.0)	1.8 (1.1)	1.38	2.1 (1.1)	1.62	2.8 (1.4)	2.15
Fifth toe	0.6 (0.6)	1.4 (1.4)	2.33	1.4 (1.4)	2.33	1.4 (1.1)	2.33
Fore foot (inside)	10.7 (4.5)	10.5 (4.9)	0.98	11.7 (4.6)	1.09	12.3 (4.4)	1.15
Fore foot (central part)	19.8 (5.9)	18.3 (5.8)	0.92	19.6 (5.3)	0.99	20.3 (6.7)	1.03
Fore foot (outside)	10.1 (4.2)	10.1 (4.5)	1.00	10.5 (4.4)	1.04	10.6 (3.8)	1.05
Mid foot	16.5 (7.8)	17.1 (9.8)	1.04	16.2 (8.4)	0.98	13.0 (7.7)	0.79
Heel[5]	31.3 (8.5)	28.8 (7.2)	0.92	21.8 (5.9)	0.70	16.5 (5.8)	0.53

1) %
2) Change ratio refers to the ratio relative to the force at the CFP position of 45 % FL.
multiple comparison (post ANOVA)
3) CFP position of 45 % FL differ from those at 55and 60 % FL, CFP position of 50 % FL differ from those at 55and 60 % FL, CFP position of 55 % FL differ from those at 60 % FL ($p<0.05$).
4) CFP position of 45 % FL differ from those at 60 % FL, CFP position of 50 % FL differ from those at 60 % FL ($p<0.05$).
5) CFP position of 45 % FL differ from those at 55and 60 % FL, CFP position of 50 % FL differ from those at 55and 60 % FL ($p<0.05$).

Table 4. Plantar pressure distribution and change ratio of Group 3 according to CFP position

n=76

Area	CFP position						
	45 % FL	50 % FL		55 % FL		60 % FL	
	Force[1] (SD)	Force (SD)	Change Ratio[2]	Force (SD)	Change Ratio	Force (SD)	Change Ratio
Total toe	5.8 (4.0)	9.3 (4.2)	1.60	12.4 (5.0)	2.14	16.2 (5.1)	2.79
Hallux[3]	3.0 (2.4)	4.8 (3.0)	1.60	6.2 (3.9)	2.07	7.3 (4.1)	2.43
Second toe[3]	0.9 (1.1)	1.4 (1.2)	1.56	2.0 (1.5)	2.22	2.9 (1.7)	3.22
Third toe[3]	1.0 (1.0)	1.5 (1.2)	1.50	2.1 (1.2)	2.10	3.2 (1.1)	3.20
Fourth toe[3]	0.7 (0.7)	1.0 (0.8)	1.43	1.4 (0.9)	2.00	2.1 (0.7)	3.00
Fifth toe	0.2 (0.5)	0.6 (0.6)	3.00	0.7 (0.7)	3.50	0.7 (0.7)	3.50
Fore foot (inside)[3]	10.1 (5.1)	13.5 (4.6)	1.34	15.2 (4.5)	1.50	15.5 (4.1)	1.53
Fore foot (central part)	18.5 (5.7)	22.5 (4.5)	1.22	23.7 (5.2)	1.28	22.8 (5.7)	1.23
Fore foot (outside)	9.9 (3.9)	10.8 (3.8)	1.09	12.1 (3.7)	1.22	12.5 (3.1)	1.26
Mid foot	17.5 (10.5)	17.0 (8.3)	0.97	17.5 (7.3)	1.00	17.9 (8.6)	1.02
Heel[4]	38.2 (10.8)	26.8 (7.0)	0.70	19.2 (6.8)	0.50	15.2 (5.5)	0.40

1) %
2) Change ratio refers to the ratio relative to the force at the CFP position of 45 % FL.
multiple comparison (post ANOVA)
3) CFP position of 45 % FL differ from those at 55 and 60 % FL, CFP position of 50 % FL differ from those at 60 % FL ($p<0.05$).
4) CFP position of 45 % FL differ from those at 50, 55 and 60 % FL, CFP position of 50 % FL differ from those at 60 % FL ($p<0.05$).

pressure at 45% FL. and 55% FL. The hallux pressure was 45% of toe pressure at CFP position of 60% FL.

Pressure on the forefoot increased with forward movement of the CFP position, and differences were seen in the inside central forefoot between 45% FL and 55% FL, 60% FL ($p<0.05$) and between 50% FL and 60% FL ($p<0.05$). No difference was apparent in the midfoot as a result of CFP position, and no variation was seen from the 45% FL position. Pressure on the heel decrease with forward movement of the CFP position, and a difference was seen between 45% FL and 50%, 55%, and 60% FL ($p<0.05$), between 50% FL and

Table 5. Comparison between plantar pressure distribution pattern and risk factors of fall

n=87

Risk factors of fall		Plantar pressure distribution pattern		
		Group 1 n=31	Group 2 n=18	Group 3 n=38
Sway of center of gravity: eyes open (cm/s)		1.8±0.5	2.0±1.2	2.1±0.8
Sway of center of gravity: eyes closed (cm/s)		2.5±0.8	2.6±1.1	3.1±1.5
Functional Reach Test (cm)		31.2±6.0	30.8±5.9	27.6±6.8
Grip (kg)	Right	24.5±8.1	21.8±6.6	20.8±6.5
	Left	21.0±6.9	20.2±6.4	18.4±5.5
Toe flexor	Right	3.9±1.4	3.8±2.6	3.2±1.0
Strength (kg)	Left	3.6±1.0	3.5±1.2	2.9±1.1
10 m walking time (s)[1]		6.7±1.0	7.1±1.6	7.6±1.6
Number of steps required to walk 10 m (steps)[1]		14.4±1.8	15.1±2.3	15.7±2.3
40 cm step test	Can perform	31 (100.0)	18 (100.0)	29 (76.3)
	Cannot perform	0 (0.0)	0 (0.0)	9 (23.7)
History of falls within	Yes	1 (3.2)	4 (22.2)	10 (26.3)
the past year[2]	No	30 (96.8)	14 (77.8)	28 (73.7)
History of near falls	Yes	10 (32.3)	7 (39.8)	22 (57.9)
within the past year	No	21 (67.7)	11 (60.2)	16 (42.1)
Fear of falling	Very afraid	4 (12.9)	6 (33.3)	8 (21.1)
	Somewhat afraid	17 (54.8)	7 (38.9)	24 (63.1)
	Not afraid	10 (32.3)	5 (27.8)	6 (15.8)

1) multiple comparison (post ANOVA), ; significant differece between Groups 1 and Groups 3 ($p<0.05$)
2) χ^2 test, $p<0.05$

60% FL ($p<0.05$).

(4) Comparison of plantar pressure distribution in 3 groups by CFP position

With a CFP position of 45% FL, pressure was higher on the hallux through third toe and lower on the heel in Group 2 than in Groups 1 and 3 ($p<0.05$).

With CFP position of 50% FL, pressure on the hallux and second toe was lower in Group 3 than in Group 1 ($p<0.05$). Pressure was lower on the second through fourth toes and higher on the midfoot in Group 3 than in Group 2 ($p<0.05$).

With CFP position of 55% FL, pressure was lower on the hallux through fourth toe in Group 3 than in Groups 1 and 2 ($p<0.05$). Pressure was also higher on the inside forefoot and midfoot in Group 3 than in Group 2 ($p<0.05$).

With a CFP position of 60% FL, pressure was lower on the hallux in Group 3 than in Groups 1 and 2 ($p<0.05$). In addition, pressure on the second and fourth toes was lower in Group 3 than in Group 1 ($p<0.05$).

3. Comparison between plantar pressure distribution pattern and risk factors of fall (Table 5)

Looking at movement ability, 10-m walking time at normal speed was 6.7 ± 1.0 s in Group 1, 7.1 ± 1.6 s in Group 2, and 7.6 ± 1.6 s in Group 3. Group 3 was thus significantly slower than in Group 1 ($p<0.05$). The number of steps needed to walk 10 m was 14.4 ± 1.8 in Group 1, 15.1 ± 2.3 in Group 2, and 15.7 ± 2.3 in Group 3. The number of steps was greater in Group 3 than in Group 1 ($p<0.05$). All subjects in Groups 1 and 2 could step up and down 40cm, compared to 29 subjects (76.3%) in Group 3 ($p<0.01$).

The number of subjects who had fallen in the previous year was 10 (26.3%) in Group 3, 4 (22.2%) in Group 2, and 1 (3.2%) in Group 1 ($p<0.05$). The number of subjects who had almost fallen in the previous year was 22 (57.9%) in Group 3, 7 (39.8%) in Group 2, and 10 (32.3%) in Group 1. A tendency toward a difference was seen. No differences were apparent in fear of falling.

No relationship was seen between plantar pressure distribution pattern and movement of the center of gravity with eyes open and eyes closed in a quiet stance, functional reach test, grip strength, or toe flexor force.

4. Comparison between plantar pressure distribution pattern and falls in the year following plantar pressure measurements

The number of subjects who experienced falls in the year following plantar pressure measurements was 2 (6.5%) in Group 1, 4 (22.2%) in Group 2, and 13 (34.2%) in Group 3 ($p<0.05$). Group 3 had the most people who experienced falls at multiple. The number of subjects who had almost fallen was 8 (25.8%) in Group 1, 6 (33.3%) in Group 2, and 19 (50.0%) in Group 3. (Table 6)

Looking at the specific conditions in which falls occurred, we see that subjects in Group 1 had fallen as a result of external forces while walking outside. Concretely, tripped when pulled by dog while walking it and Lost balance from strong winds walking through a typhoon. Falls in Group 2 occurred in risky areas such as the bath or entryway steps in the home. For instance, it is slipped when a bathmat shifted and tripped on a step at the front entrance to home. Most falls in Group 3 occurred with no special inducement while walking in flat areas around the home or neighborhood. For instance, it is lost balance for no particular reason at a place without steps while

Table 6. Comparison between plantar pressure distribution pattern and falls in 1-year period after measurement of plantar pressure

n=87

Item	Plantar pressure distribution pattern		
	Group 1 n=31	Group 2 n=18	Group 3 n=38
Falls within 1-year period after measurement	2 (6.5)	4 (22.2)	13 (34.2) *
Of these, falls at multiple	0 (0.0)	1 (25.0)	6 (46.2)
Near falls in 1-year period after measurement	8 (25.8)	6 (33.3)	19 (50.0) *

* χ^2 test, $p<0.05$

Table 7. Circumstance of fall according to plantar pressure distribution pattern

Plantar pressure distribution	Circumstance of fall
Group 1	・ Tripped when pulled by dog while walking it ・ Lost balance from strong winds walking through a typhoon
Group 2	・ Slipped when a bathmat shifted ・ Tripped on a step at the front entrance to home while walking with a grocery bag ・ Distracted by a conversation with a guest, tripped on a step at the front entrance to home
Group 3	・ Lost balance for no particular reason at a place without steps while walking at home ・ Stumbled while trying to go to the bathroom during the night ・ Tripped while going for a walk on a flat road in the neighborhood ・ Lost footing on a step while walking through the neighborhood ・ Slipped on a stone in the yard ・ Pushed by a crowd while walking through an inn ・ Lost footing when carelessly tried to get into the car

Table 8. RR of plantar pressure distribution pattern and risk factors of fall

n=87

Item	Divison	Falls	Non falls	RR[1)]
Pantar pressure distribution pattern	Group 1	2	29	1.0
	Group 2	4	14	2.0
	Group 3	13	25	4.0
Age (year)	75<	9	32	1.0
	75≧	10	36	1.0
History of falls	No	9	63	1.0
	Yes	10	5	2.0
Functional Reach Test (cm)	15<	18	68	1.0
	15≧	1	1	1.6
Grip (kg)	21.7<	6	28	1.0
	21.7≧	13	40	1.3
Toe flexor Strength (kg)	2.5<	7	39	1.0
	2.5≧	12	29	1.6
10 m walking time (s)	7.2<	11	59	1.0
	7.2≧	8	9	1.5

1) RR : Relative risk

walking at home and stumbled while trying to go to the bathroom during the night (Table 7)

5. Relative risk of plantar pressure distribution pattern and risk factors of fall (Table 8)

The relative risk in Group 3, classified according to their plantar pressure distribution pattern, was highest: 4.0. Those involved in the primary factors related to falls, such as muscle strength, balance, age, and plantar flexor muscles, which have recently being studied more closely, were low: 1 to 2.

Discussion

Our original study focused on slight losses of balance as a cause of falls in the elderly. We quantitatively investigated relationships between standing position and plantar pressure, and revealed a relationship between plantar pressure idistribution and falls.

1. Plantar pressure distribution in elderly people in a standing posture

The focus of this study was the fluctuations in the plantar pressure distribution from the most stable upright resting position to CFP 60% FL, which is the stable range in the anterior direction of the standing position.

Mean CFP position in a quiet stance was 43.3% FL. This result resembles the findings of a previous study[7-10], and no difference in age was seen in the quiet stance position.

Regarding the plantar pressure distribution of the arch, in CFP position 45% FL, the pressure on the forefoot and heel was approximately 40%, respectively. In the forefoot, pressure in the central part accounted for 50% and pressure in the inside and outside parts accounted for about 25% each. The central part of the forefoot corresponds anatomically to the second and third anterior metatarsal. The subjects of the previous studies were adults, but the results were the same as those for this study[11-17].

With the forward lean, the plantar pressure distribution of the forefoot and the mid foot was constant, and there was a decrease in the heel pressure.It has been reported that there were no fluctuations in the adult study[6]. The reason that

both the elderly and the adults had no fluctuations in the forefoot region was that structurally, the arch of the foot is strongly immobilized by muscles and ligaments. In addition, the second metatarsal bone is immobilized at the base. Thus, it is inferred that even if there are fluctuations in CFP position in the stable range of the standing position, the pressure on the forefoot did not fluctuate greatly. In the case of the heel, a decrease in the flexibility of the ankle joints has been noted in the elderly in comparison to adults; therefore, the pressure was seen to have decreased from the early stage of the forward lean. The foot has an arch structure so that weight can be distributed back and forth to enhance stability in the standing position[23], and as adults near the forward-most lean position, the stability decreases considerably and the pressure on the forefoot increases[6]. The forward-most lean refers to 70 to 80% of the foot length from the heel[9·24]. From the foregoing, due to the fact that in the elderly, the postural maintenance function of the arch in standing position is reduced, the plantar pressure distribution had changed even before reaching the CFP position 60% FL, which is thought to be the stable range in the standing position.

The pressure in the CFP position 45% FL occupied about 7% of total plantar pressure. In the study for adults, the results indicated 3–4%[6·14], which meant that the plantar pressure in the elderly was approximately twice that in adults. Furthermore, as the degree of forward lean increased, the pressure also increased. The toes had widened their support area[25-27], and the tension of the plantar aponeurosis increased in proportion to the increase in the toe pressure[28]. Deep underneath the plantar aponeurosis is the plantar fixator muscle, and by the moving of the metatarsophalangeal joint, the longitudinal arch can be actively adjusted. In other words, through the increase in the base of support and the retention of the longitudinal arch, the toes can have increased stability in the standing position. From the high readings in the toe pressure of the elderly in even the upright resting position in comparison to those of the adults, it can be concluded that the postural maintenance function of the arch in standing position is seen to decline in the elderly.

As a result of comparing the plantar pressure distribution in the individual elderly subjects, 3 characteristic patterns were found. By comparing this to the aforementioned plantar pressure distribution in adults, all 3 patterns indicate that the postural maintenance function of the arch have declined in comparison to that of adults, and the capability of the toes which compensates for this function differs among the elderly, thus accounting for the broad division into 3 categories.

2. Relationship between plantar pressure distribution pattern and falls in the elderly with standing posture

The fall factors related to the plantar pressure distribution pattern were the ability to walk and fall experience. In other words, many in the group with low toe pressure both in the upright resting position and in the forward lean position had low walking speed as well as fall experience. The kicking out motion when walking is a result of the flexor muscle activities in the toes. In addition, the flexor muscle activities in the toes and the increase in toe pressure in standing position contribute to the retention of the longitudinal arch. Therefore, the common factor in the plantar pressure distribution when walking and postural maintenance when standing is the toe function. Consequently, the declining of the toe function is possibly related to the occurrence of falls.

In the group in which toe pressure was low in both a quiet stance position and 60% FL, many subjects had multiple fallen during the year after the measurements. These falls showed no particular inducement and occurred while they were walking normally in flat areas around their home or neighborhood. These falls occurred with a slight loss of balance, suggesting that characteristic falls in the elderly may be predictable based on plantar pressure distributions.

A relationship was also seen between plantar pressure and walking ability, which is a key factor in falls. Enlargement of the body weight support surface and propulsion have been demonstrated to

be functions of the toes during walking[25-27], but a common toe function may affect standing posture and walking.

The relative risk in Group 3, classified according to their plantar pressure distribution pattern, was highest: 4.0. Those involved in the primary factors related to falls, such as muscle strength, balance, age, and plantar flexor muscles, which have recently being studied more closely, were low: 1 to 2.

3. Applications to nursing

A relationship was seen between falls and plantar pressure in community-dwelling elderly, which indicates the stability of standing posture. This suggests that plantar pressure distribution in standing posture may be one predictor of fall patterns, and toe interventions may be effective in preventing falls.

4. Limitations and issues

The number of subjects in this study was small and since the present data were classified according to our criteria, projection of the present findings to the general population is not feasible. However, since a relationship with falls was seen, the stability of standing posture was confirmed as a useful perspective for examining falls in the elderly. Future studies will need to increase the number of subjects, clarify the relationship between toe flexors and plantar pressure, develop better predictors of fall risks, and investigate interventions for feet that increase stability in standing postures.

Conclusion

The purpose of this study was to clarify the characteristics of plantar pressure distribution while the community-dwelling elderly were standing, and to investigate the relationship between plantar pressure distribution and falls.

To prevent falls in the elderly, we focused on stability in standing posture and quantitatively investigated plantar pressure distribution. Characteristics of toe pressure showed 3 patterns related to falls. This suggests that plantar pressure distribution in a standing posture may be one indicator for predicting falls may be effective in preventing falls.

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地域高齢者の立位姿勢における足底圧分布の特徴および転倒との関係

平松　知子，泉　キヨ子

要　　旨

【目的】：地域高齢者の立位姿勢における足底圧分布の特徴を明らかにした。さらに、転倒との関係を検討した。**【方法】**：日常生活の自立した地域高齢者87名（75.0±6.4歳）を対象として、足底圧計測システムに経年的に蓄積された安静立位から前傾に至るデータを取得した。足弓部を5分割（前足3分割、中足、踵）、足指部を5分割（足指毎）し、足圧中心（CFP）が踵から足長に対して45%の位置（以下45%FL）、50%FL、55%FL、60%FLの足底圧を算出した。CFP位置は、45%FLは平均安静立位位置であり、60%FLまでは成人の立位姿勢の前方向の安定域とされていることから選択した。各部位の足底圧は、一側の全足底圧に対する相対値（%）で示した。個々のデータ間を比較し、足指圧の変動の相違が特徴的であったことから、CFP位置45% FLと60% FLにおける足指圧の平均値を基準として足底圧分布を類型化した。さらに、転倒との関連を検討した。**【結果】**：足底圧に左右差および経年的な変化はみられなかった。足底圧分布は、CFP位置45%FLの足指圧が低値であり、60%FLは高値であるⅠ群、2地点とも高値であるⅡ群、2地点とも低値であるⅢ群に分類された。3群とも、前傾に伴い足指圧も増加していた。足弓部の圧は、前足と中足は変化なく、踵は減少していた。3群と転倒要因である歩行速度および転倒経験に関連がみられた。また、測定後1年間の転倒発生はⅢ群に多く、相対危険比は4.0であった。**【結論】**：高齢者の転倒予防のために立位姿勢の安定性に注目して足底圧分布を量的に検討した。足指圧の特徴から3パターンを見出し、転倒との関連がみられたことから、立位姿勢における足底圧分布は転倒予測指標の1つとなる可能性が示唆された。