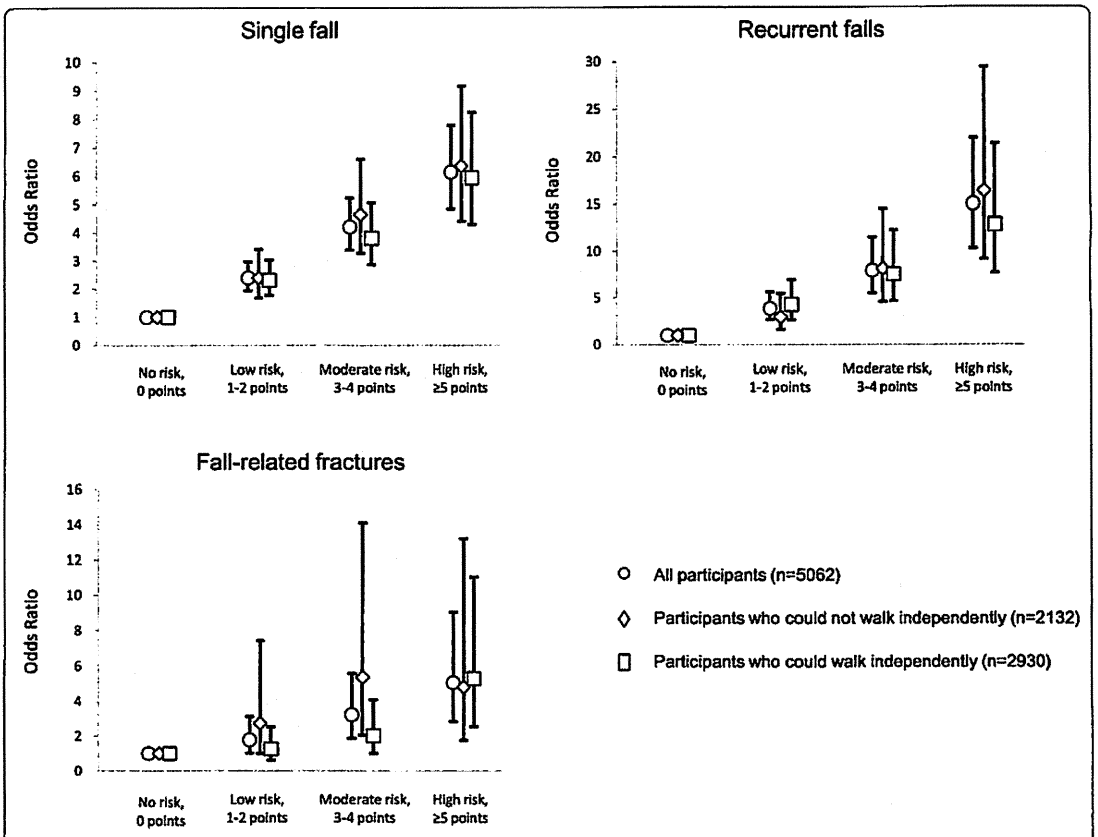

Figure 2 Odds ratios and 95% confidence intervals of SRRST categories for a single fall, recurrent falls, and fall-related fractures. Models were adjusted for all confounding factors (model 2). The participants were divided into dependent-walking and independent-walking groups.

Table 4 Sensitivity and specificity of SRRST scores for falls and fall-related fractures

SRRST score	Single fall		Recurrent falls		Fractures	
	Sensitivity (95% CI)	Specificity (95% CI)	Sensitivity (95% CI)	Specificity (95% CI)	Sensitivity (95% CI)	Specificity (95% CI)
0/1 point	0.91 (0.90 to 0.92)	0.30 (0.29 to 0.32)	0.96 (0.94 to 0.97)	0.28 (0.26 to 0.29)	0.90 (0.85 to 0.94)	0.24 (0.23 to 0.26)
1/2 point	0.80 (0.78 to 0.82)	0.47 (0.45 to 0.49)	0.87 (0.85 to 0.90)	0.44 (0.42 to 0.45)	0.79 (0.72 to 0.84)	0.39 (0.38 to 0.41)
2/3 point	0.66 (0.63 to 0.68)	0.63 (0.61 to 0.64)	0.75 (0.72 to 0.78)	0.60 (0.58 to 0.61)	0.68 (0.61 to 0.74)	0.55 (0.53 to 0.56)
3/4 point	0.48 (0.46 to 0.51)	0.76 (0.75 to 0.78)	0.58 (0.55 to 0.62)	0.74 (0.73 to 0.76)	0.50 (0.43 to 0.57)	0.70 (0.68 to 0.71)
4/5 point	0.30 (0.28 to 0.32)	0.87 (0.86 to 0.88)	0.39 (0.36 to 0.42)	0.86 (0.85 to 0.87)	0.32 (0.26 to 0.39)	0.82 (0.81 to 0.83)
5/6 point	0.14 (0.13 to 0.16)	0.94 (0.93 to 0.95)	0.22 (0.20 to 0.25)	0.93 (0.92 to 0.94)	0.13 (0.09 to 0.19)	0.91 (0.90 to 0.92)
6/7 point	0.07 (0.06 to 0.09)	0.97 (0.97 to 0.98)	0.10 (0.08 to 0.12)	0.97 (0.96 to 0.97)	0.02 (0.01 to 0.05)	0.96 (0.95 to 0.96)

Multiple regression models revealed that the SRRST score was associated with falling as well as fall-related fracture, even when adjusted for many confounding factors. Odds ratios were markedly higher for recurrent falls than for single fall and fall-related fractures. A previous study suggested that infrequent or isolated falls are more unpredictable events than multiple falls and less likely to result from underlying neurologic or musculoskeletal problems [18]. The incidence of fall-related fractures is also influenced by low bone density which was not measured in this study [26-28]. These factors may have weakened the relationships between the SRRST and a single fall and fall-related fractures. Higher odds ratios, however, remained between the SRRST and history of falling and fractures than previously reported odds ratios calculated from the cut-off points of objective performance tests in frail elderly people who participated in the TOUCH [7]. Cut-points for maximizing the sensitivity and specificity were 2/3 point in all of a single fall, recurrent falls and fall-related fractures. Care providers may require attention to risk of falls and fall-related fractures in the frail elderly adults who have a score 3 points and over in the SRRST.

Why did staff assessments show close relationships with falls and fall-related fractures? Falling is induced by multidimensional factors, and the primary cause of falling may vary among frail elderly adults who have many risk factors for falls. Thus, it is difficult to determine the primary risks for falls in all frail elderly adults using objective measures that can identify only specific issues. In contrast, subjective evaluations can determine combined risks of falling based on various information such as physical functions, daily activity status, and risky behaviors, although these evaluations cannot give clear, specific and objective risks for falling. The combined information is important for identifying risks of falls and preventing falls in frail elderly people, because correct risk-assessments by care staff may lead to successful assessment and interventions for preventing falls [29,30]. We reported previously that an intervention study using supervision technique based on the assessment of fall-risk behaviors can reduce the risk of falling in institutionalized elderly people [31]. Thus, we considered that the assessment and intervention used in the SRRST may be useful for preventing falls in frail elderly people. Furthermore, the SRRST has the strength of being designed for frail elderly people. Although risk factors for falls differ between elderly adults who can and cannot stand unaided [32], nearly all risks identified by the SRRST showed significant odds ratios for falls and fall-related fractures in the dependent walking and independent walking groups. Future research should include a prospective measurement of falls in order to more accurately determine the validity of the SRRST for this population and perform an intervention study to reveal the effects of the SRRST on intervention.

One of the limitations of our study is that we performed a cross-sectional study and analysed retrospectively recalled falls. This is known to be a less accurate measure than prospectively recalled falls [33]. It is possible that underreporting of falls by participants may have led an underestimation of the rates of falls. Therefore, further investigation of the validity of these tests in predicting falls in frail elderly people using a prospective study design is recommended. Second, the investigations of the SRRST and history of falls were investigated at the same time. Thus, the information of the history of falls might affect subjective judgments of the testers. However, correct judgments of the SRRST may require multidimensional information included the history of falls in the elderly adults and testers, i.e. care providers, may know history of falls of their clients through daily care. In other words, testers who had information of falls history in the subjects could measure correctly the risk of falls using the SRRST.

Conclusion

In conclusion, this study developed the SRRST as a subjective assessment for identifying risk of falls in the frail elderly people. Numerous studies developed fall risk assessment tools which evaluate using objective physical or cognitive measurements [2]. Unfortunately, some frail elderly adults cannot perform objective assessments to screen fall risks although these assessment tools may judge almost frail elderly as high risk individuals and identify multiple risks for falling [7]. The SRRST can evaluate easily the specific fall risks and have high feasibility in the elderly. This study provides the evidence that subjective assessment by staff was associated with risk of falling and fall-related fractures in frail elderly people. We encourage providing a fall prevention strategy to the frail elderly who had some risks for falls in your subjective judgments. Future research need to determine the predictive validity of incidence of falls and fractures in the frail elderly people.

Abbreviations

SRRST: Subjective Risk Rating of Specific Tasks; TOUCH: Tsukui Ordered Useful Care for Health; ICC: intraclass correlation coefficient; OR: Odds Ratio; 95% CI: 95% confidence interval.

Acknowledgements

This work received financial support from a Grant-in-Aid for Scientific Research from the Ministry of Education, Culture, Sports, Science and Technology of Japan (Tokyo, Japan).

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Authors' contributions
HS and MS were responsible for the study concept and design. HS was responsible for the draft of the manuscript. MI, TI, KH, and TS were responsible for the critical revision of the manuscript for important intellectual content. KK was responsible for the coordination of acquisition of data. All authors were responsible for the final approval of the manuscript.

Competing interests
The authors declare that they have no competing interests.

Received: 9 August 2010 Accepted: 12 August 2011
Published: 12 August 2011

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Pre-publication history
The pre-publication history for this paper can be accessed here:
http://www.biomedcentral.com/1471-2318/11/40/prepub

doi:10.1186/1471-2318-11-40
Cite this article as: Shimada *et al.*: Relationship between subjective fall risk assessment and falls and fall-related fractures in frail elderly people. *BMC Geriatrics* 2011 11:40.

J Orthop Sci (2011) 16:418–423
DOI 10.1007/s00776-011-0089-4

ORIGINAL ARTICLE

Serum 25-hydroxyvitamin D status in hip and spine-fracture patients in Japan

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Received: 29 September 2010 / Accepted: 12 April 2011 / Published online: 19 May 2011
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Abstract

Background Serum 25-hydroxyvitamin D (25(OH)D) is used as an index that reflects the level of vitamin D. We have previously reported, on the basis of a study in Sado in Niigata, that patients with hip fracture have lower serum 25(OH)D levels than non-hip-fracture cases. In this study, the serum 25(OH)D status in hip-fracture cases was examined in four regions in Japan. Although most hip-fracture patients have experienced past spine-compression fractures, the relationship of these fractures and 25(OH)D is unknown. Therefore, we also examined the 25(OH)D level in spine-compression fracture patients in the same locations and time periods.

Methods The levels of 25(OH)D, intact parathyroid hormone (intact PTH), undercarboxylated osteocalcin (ucOC), urine *N*-terminal crosslinking telopeptide of type I collagen (NTX), and bone mineral density were examined in patients with hip and spine fracture due to osteoporosis in several regions in Japan.

Results There were no significant differences in age, BMI, serum 25(OH)D, serum intact PTH, and serum ucOC among the regions. Levels of serum 25(OH)D were low in patients with hip fracture and spine fracture. The average serum 25(OH)D level was significantly lower in hip-fracture patients than in spine-fracture patients (16.3 vs. 18.1 ng/mL, $P < 0.05$). High serum ucOC was found in 37% of hip-fracture patients and 44% of spine-fracture patients.

Conclusions Both hip and spine-fracture patients have vitamin D insufficiency, with similar results found in elderly patients in four areas of Japan. The severity of this condition tends to be more serious in hip-fracture patients than in spine-fracture patients.

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Introduction

Osteoporosis causes fractures, serious physical and mental damage, and decreased activities of daily living (ADL) and quality of life (QOL). Hip fractures and vertebral compression fractures are especially common in elderly people [1, 2], and the negative effects of these fractures on ADL and QOL emphasize the need to determine the associated

Table 1 Number of patients in the study

	Hip fracture					Spine fracture				
	Sado	Aichi	Tottori	Kumamoto	Total	Sado	Aichi	Tottori	Kumamoto	Total
Male	14	11	12	15	52	4	6	2	0	12
Female	52	37	26	58	173	27	14	11	0	52
Total	66	48	38	73	225	31	20	13	0	64

risks and causes and to establish preventive measures. A relationship between serum vitamin D (25(OH)D; 25-hydroxyvitamin D) level and hip fracture has been established. Overseas [3, 4] and domestic reports, including an epidemiologic survey in Sado City in Niigata Prefecture in 2004 [5], have shown that 25(OH)D is significantly lower in hip-fracture patients than in controls. Furthermore, half of Japanese women aged >65 years old also have insufficient levels of serum 25(OH)D [6, 7], and this may be a major risk factor for hip fracture.

Epidemiologic surveys suggest that the incidence of hip fracture is lower in Japan than in Europe and the United States [8–10], and there are also regional differences in Japan. Furthermore, because most hip-fracture patients (81.8%) have past vertebral compression fracture on X-ray [5], the relationship of compression fracture and serum 25(OH)D is of concern. In this study, the relationship between serum 25(OH)D and hip fracture was examined from a perspective of regional differences in Japan. We also aimed to clarify the relationship between spine fracture and serum vitamin D level, and to examine the vitamin K status of patients with hip fracture or spine fracture.

Patients and methods

Study site

A survey of patients treated for hip fracture and spine-compression fracture was performed in one or two hospitals in several areas of Japan: Niigata (Sado), Aichi, Tottori, and Kumamoto prefectures.

Subjects

The subjects were inpatients and outpatients aged ≥65 years old with fresh hip and spine-compression fracture treated from April 1, 2007 to March 31, 2008. All patients gave consent to the study. For compression fracture, it was not always easy to identify a new fracture. However, patients who visited the hospital for symptoms such as back pain and were judged, on the basis of X-ray and physical examination by an orthopedic doctor, to have a fresh vertebral fracture were considered as a case of new fracture (an incident of fracture: clinical fracture).

There were 102, 81, 57, and 90 subjects from Sado, Aichi, Tottori, and Kumamoto, respectively. Of these 330 patients, 16 with a tumor, osteomalacia, bone fracture due to systemic diseases, hyperthyroidism, hyperparathyroidism, renal failure, or dialysis were excluded. This left 314 patients (66 males, 247 females, 1 unknown) for whom data were collected. Of these patients, data were analyzed for 289 (225 cases of hip fracture and 64 of spine fracture; Table 1) after exclusion of patients who had taken drugs such as active vitamin D, vitamin K, and bisphosphonate, and one patient of unknown sex.

There were more patients with hip fracture than with spine-compression fracture in this study. Epidemiologically, there were more patients with spine fracture than hip fracture, but those with spine fracture were mainly outpatients. This reduced the number of cases of spine fracture in the analysis, and there was no selective exclusion of spine-fracture patients in the study.

Measurements

Data were collected for body height and weight (body mass index, BMI), serum 25(OH)D, serum intact PTH (intact parathyroid hormone), urine NTX (*N*-terminal crosslinking telopeptide of type I collagen), serum undercarboxylated osteocalcin (ucOC), bone mineral density (BMD) in the hip, and history of fractures of other bones, including the spine, hip, distal radius, and proximal humerus. Blood samples for biochemical assays were collected within 1 week after fracture. The exact date of spine fracture was often uncertain, but most data were collected within 1 week after the first medical examination.

The serum 25(OH)D level was measured by enzyme-linked immunosorbent assay (ELISA) assay using a kit supplied by DiaSorin (Stillwater, MN, USA). A serum 25(OH)D level of at least 15–20 ng/mL is needed to optimize PTH levels, on the basis of several reports. Hollis et al. [11] found that the normal range of 25(OH) D was 32–100 ng/mL and that a concentration of <10 ng/mL indicated a vitamin D-deficient state. Other studies performed in the USA and Australia [12, 13] show that a serum 25(OH) D level of at least 15–20 ng/mL is needed to

achieve an optimum PTH level, and therefore we defined a 25(OH) D level of <20 ng/mL as vitamin D insufficiency.

Serum-intact PTH was measured by means of an electrochemiluminescence immunoassay (ECLIA) (Roche Diagnostics, Basel, Switzerland), in which intact PTH molecules are detected; the normal range is 10–65 pg/mL [14, 15]. We note that Segersten et al. [16] have suggested that the upper limit of the normal range for PTH may be too high; however, LeBoff et al. [4] used a value of 65 pg/mL, and we also chose 65 pg/mL as the upper limit of the normal range for intact PTH.

The urine NTX assay was performed using an Osteomark NTX ELISA kit (Inverness Medical Professional Diagnostics, Princeton, NJ, USA). Serum ucOC was measured by ECLIA (Sanko Junyaku, Tokyo, Japan). A high level of serum ucOC is a reported risk factor for hip fracture [17, 18]. In patients with vitamin K insufficiency, osteocalcin (OC) (a basic bone protein produced by osteoblasts) is released into blood as ucOC, which has a glutamic acid (Glu) residue that is not converted to a γ-carboxyl glutamate. This reduces OC incorporation into bone. The cutoff value for serum ucOC is 4.5 ng/mL [19, 20].

BMD of the hip was measured by dual-energy X-ray absorptiometry (DXA) (in Sado: Hologic 4500A, Bedford, MA, USA; in Aichi: DPX-NT; GE Medical Systems Lunar, Madison, WI, USA; in Kumamoto: Hologic Delphi, Bedford, MA, USA). In hip-fracture cases, BMD was measured in the hip on the opposite side to the fractured hip. Data for past fractures of the hip, spine, distal radius, and proximal humerus were determined by interview or X-ray.

Statistical analysis

Comparison between two groups was performed using a non-paired t test for parametric variables and a Mann–Whitney U test for non-parametric variables. Comparison among multiple groups was performed using ANOVA, followed by a Tukey test for parametric variables and a Kruskal–Wallis test for non-parametric variables. Analysis was performed using Microsoft Excel 2007 and Ekuseru Toukei 2008 for Windows.

Ethical considerations

The study plan was approved by the Japanese Orthopedics Association Ethical Review Board. The study was explained in writing to the patients and informed consent was obtained.

Results

Data were collected for 66 cases of hip fracture (52 females and 14 males) and 31 of spine-compression fracture (27 females and 4 males) in Sado City, Niigata (an island city) (Table 1); for 48 cases of hip fracture (37 females, 11 males) and 20 of spine fracture (14 females and 6 males) in Aichi Prefecture (National Center for Geriatrics and Gerontology); for 38 cases of hip fracture (26 females and 12 males) and 13 of spine fracture (11 females and 2 males) in Tottori Prefecture (including patients in three hospitals); and for 73 cases of hip fracture (58 females and 15 males) and 0 of spine fracture in Kumamoto Prefecture (Tamana Central Hospital).

Data in the four regions

The average values of variables in each region are shown in Table 2. The average age at the time of injury ranged from 82 to 84 years old for hip-fracture cases, with no significant differences among the regions. For BMI in hip-fracture patients also there were no significant differences among regions. The order of BMI in spine fracture was Tottori > Sado > Aichi, with no significant differences among regions. The average levels of serum 25(OH)D (<17 ng/mL) in hip-fracture patients were low in all four areas. These values were especially low in Sado and Aichi, but there were no significant differences among the regions. The mean serum 25(OH)D level was 17–19 ng/mL in spine-fracture cases, and was lowest in Sado, but again with no significant regional differences.

The average serum intact PTH level (>45 pg/mL) in hip-fracture patients was comparatively high in all four areas, with no significant regional differences. This level ranged from 40 to 47 pg/mL in spine-fracture patients, and there were also no significant differences among the areas.

In patients with hip fracture, urine NTX was significantly higher in Aichi and Sado than in Kumamoto ($P < 0.01$ and $P < 0.05$, respectively). There were no significant differences in urine NTX in spine-fracture patients among the regions.

Data for serum ucOC were collected from Sado, Tottori, and Kumamoto, and showed no significant differences among these areas. BMD analysis was performed in Sado, Aichi, and Kumamoto. Because radial and spine BMD were measured in Tottori, we excluded these data from the analysis. BMD in hip-fracture patients in Sado was significantly lower than that in Aichi ($P < 0.001$). There were no significant differences in BMD in spine-fracture patients among the regions.

Comparison of hip and spine fracture

A comparison of variables in hip and spine-fracture cases is shown in Table 3. The average age over all regions was significantly higher for hip fracture than for spine fracture (83.0 vs. 80.1 years old, $P < 0.01$). BMI showed no

Table 2 Average values of variables for cases of hip and spine fracture in each region (mean ± SD)

	Variables/ Regions	Age (years old)	BMI (kg/m²)	Serum 25(OH)D (ng/mL)	Serum intact PTH (pg/mL)	Urine NTX-cre (nmol BCE/nmol Cr)	Serum ucOC (ng/mL)	BMD (g/cm2)
Hip fracture (n=225)	Sado	84.3±7.83	20.1±3.34	16.0±5.61	55.0±53.6	98.6±52.5	4.48±4.49	0.465±0.164
	Aichi	82.2±9.38	19.6±4.01	15.5±4.88	46.8±19.04	107.6±63.8	-	0.585±0.144
	Tottori	83.2±8.07	21.2±3.64	17.1±5.41	46.3±23.6	84.0±46.2	4.57±3.34	
	Kumamoto	82.3±11.5	20.2±3.05	16.9±4.48	59.7±31.5	73.7±42.5	4.61±4.50	0.535±0.140
Spine fracture (n=64)	Sado	79.6±6.67	21.8±5.56	17.5±6.00	47.3±18.1	76.8±46.8	6.61±5.59	0.522±0.164
	Aichi	81.7±5.85	20.3±6.04	19.2±5.05	41.9±22.1	92.8±44.4	-	0.590±0.203
	Tottori	79.2±5.85	22.4±2.49	17.7±5.5	43.7±17.0	67.7±26.2	5.18±2.83	-
	Kumamoto	-	-	-	-	-	-	-

* $P < 0.05$, ** $P < 0.01$

Table 3 Average values of variables for cases of hip and spine fracture

Variables	Hip fracture	Spine fracture	P value
Age (years old)	83.0 ± 9.51	80.1 ± 6.26	$P < 0.01$
BMI (kg/m²)	20.5 ± 3.49	21.4 ± 5.15	n.s.
Serum 25-OHD (ng/mL)	16.3 ± 5.13	18.1 ± 5.59	$P < 0.05$
Serum intact PTH (pg/mL)	53.3 ± 36.8	44.9 ± 19.1	n.s.
Urine NTX (nmol BCE/nmol Cr)	89.9 ± 53.5	80.5 ± 42.9	n.s.
Serum ucOC (ng/mL)	4.55 ± 4.25	6.18 ± 4.95	$P < 0.01$
BMD (g/cm²)	0.521 ± 0.163	0.616 ± 0.136	$P < 0.01$

significant difference between hip and spine cases, but the average BMI in spine-fracture patients tended to be higher than that in hip-fracture patients. The average 25(OH)D level in hip-fracture patients was significantly lower than that in spine-fracture patients (16.3 vs. 18.1 ng/mL, $P < 0.05$). There were no significant differences in intact PTH between hip and spine-fracture cases, but the average intact PTH in hip-fracture patients tended to be higher than that in spine-fracture patients.

Urine NTX was elevated in both fracture types, with no significant difference between the two types. The average serum ucOC level was significantly lower in patients with hip fracture than in those with spine fracture (4.55 vs. 6.18 ng/mL, $P < 0.01$). BMD was low for both types of fracture, and mean BMD for all hip-fracture cases was significantly lower than that for all spine-fracture cases (0.521 vs. 0.616 mg/cm², $P < 0.001$).

The percentages of patients with 25(OH)D <20 ng/mL were 79.0% for hip-fracture cases and 66.7% for spine-fracture cases (Fig. 1). Data for ucOC were available for Sado, Tottori, and Kumamoto. In these regions, the percentages of patients with ucOC ≥ 4.5 ng/mL were 36.2% in hip-fracture cases and 50.0% in spine-fracture cases (Fig. 2).

Past fractures

For evaluation of past fracture, asymptomatic spine-compression fracture was evaluated on the basis of X-ray only in Sado. This analysis showed that 83.3% of hip-fracture patients had past fracture. These data in other areas were obtained by interview, and indicated that 16.7–20.5% of hip-fracture patients had past fractures (Table 4). The percentage of patients with past fracture among spine-fracture patients ranged from 12.9 to 25.0%. Past spine-compression fracture was most common in both hip and spine-fracture patients. Because the data range was wide and there was a large difference between the fractures counted by interview and those assessed by X-ray, including asymptomatic

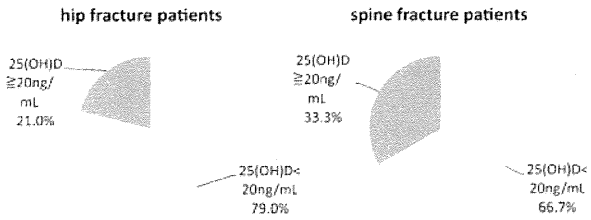

Fig. 1 Percentages of patients with hip or spine fracture with high and low serum 25-OHD levels. The percentages of patients with 25(OH)D < 20 ng/mL were 79.0% in hip-fracture cases and 66.7% in spine-fracture cases

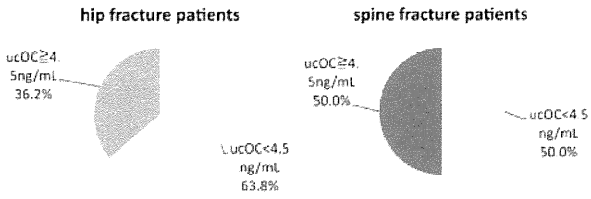

Fig. 2 Percentages of patients with hip or spine fracture with high and low serum ucOC levels. The percentages of patients with ucOC ≥ 4.5 ng/mL were 36.2% in hip-fracture cases and 50.0% in spine-fracture cases

Table 4 Numbers of patients who had past fracture

Area	Patients with hip fracture *N* (%)	Patients with spine fracture *N* (%)
Sado	55[a] (83.3)	4 (12.9)
Aichi	8 (16.7)	5 (25.0)
Tottori	7 (18.4)	3 (21.4)
Kumamoto	15 (20.5)	–

N, number of patients who had past fractures (spine, hip, distal radius, and proximal humerus)

[a] Asymptomatic past spine-compression fracture was assessed by X-ray in Sado. Other data were obtained by interview

compression fracture, we concluded that accurate information on past fractures cannot be obtained by interview.

Discussion

Serum 25 (OH)D and ucOC status

The serum 25(OH)D was low in both hip and spine-fracture patients in all four areas (<20 ng/mL). Intact PTH was slightly elevated in both fracture types and all areas. Low 25(OH)D (vitamin D insufficiency) leads to a high level of intact PTH, indicating slight secondary hyperparathyroidism.

Serum 25(OH)D differences caused by changes in daylight hours at different latitudes are thought to affect the incidence of hip fracture, but this study showed no marked regional differences for either fracture type. However, because data from Northern Japan were not included in this study, it is unclear whether there is any regional difference in an area of higher latitude than Sado.

Fewer fermented soybeans (Natto) are consumed in Western Japan than in the Eastern part of the country [21], and ucOC levels can be viewed in this context. However, there were no significant regional differences in these levels in this study.

Comparison of hip and spine fracture

We also examined differences between hip and spine fractures. The average age at the time of injury was 2.4 years older for hip-fracture cases than for spine-fracture cases ($P < 0.01$). Because approximately 80% of patients with hip fracture also have spine fracture [5], this suggests a chain of events of vitamin D insufficiency → bone absorption acceleration → spine fracture → hip fracture.

The 25(OH)D level was lower ($P < 0.05$) and intact PTH tended to be higher (N.S.) in hip-fracture patients than in spine-fracture patients (Table 3). Low 25(OH)D was more common in hip fracture, and almost two-thirds of spine-fracture patients also had low 25(OH)D (Fig. 1). These results indicate that vitamin D insufficiency and resulting slight hyperparathyroidism were present in patients with both kinds of fracture. These conditions were more severe in hip-fracture patients, which is consistent with the chain of events described above.

The ucOC level was higher in spine fracture than in hip fracture ($P < 0.01$) (Table 3). High ucOC was found in half of the spine-fracture patients, but only one-third of the hip-fracture patients (Fig. 2). That is, vitamin K deficiency was more serious in spine-fracture patients than in hip-fracture patients. However, other factors tended to be more severe in hip-fracture patients. This contradictory result might be because of a change in the serum ucOC level in the period after fracture and before measurement. Blood samples may not always have been collected within 1 week after fracture in spine-fracture cases, because it was not always clear when the fracture had occurred. Therefore, we cannot exclude the possibility of a change in the serum ucOC level in the period after fracture.

Tsugawa et al. [22] reported that the incidence of vertebral fracture in patients with a low plasma phylloquinone (K_1) concentration was significantly higher than that in those with a high K_1 level. However, the ucOC level has not been compared between cases of hip and spine fracture, and clarification of this issue requires further study.

This study was performed in several areas across Japan. The results indicated that differences between hip and

spine fracture were more significant than regional differences. We note that our data do not cover the entire country and further studies of regional differences are required. However, there are few spine-fracture cases in some regions and values for BMD and ucOC are not available in some areas, which may prevent complete analysis. Within this limitation, our results show that both hip and spine-fracture patients have vitamin D insufficiency, which is a risk factor for fracture, based on measurement of serum 25(OH)D and other factors in elderly patients in four areas of Japan. The severity of this condition was more serious in hip-fracture patients.

Acknowledgments We thank the orthopedic departments of the institutions that contributed to this study. We are especially grateful to Drs M Takemura, Y Terabe and T Hida, National Center for Geriatrics and Gerontology, Dr M Shimizu, Shimizu Hospital, Dr M Nakashima, Nojima Hospital, and Drs A Hattori and T Oinuma, Sado General Hospital, for their cooperation. The study could not have been completed without the assistance of all the orthopedic surgeons and numerous other health-care professionals. We express our gratitude to all the individuals who assisted with the study. We also thank Dr Naohito Tanabe, Department of Public Health, Niigata University Graduate School of Medical and Dental Sciences, for advice on statistical analysis. This study was funded by the Committee on Osteoporosis of the Japan Orthopedic Association (we especially thank Drs K Sakamoto, E Ibi, K Aoyagi, K Kita, K Yamazaki, N Yamamoto, T Nakamura, and R Toyoshima) and partially supported by a grant-in-aid from the Ministry of Health, Labor and Welfare of Japan (grant H18-Choujyu Ippann-036).

Conflict of interest The authors did not receive and will not receive any benefits and funding from any commercial party related directly or indirectly to the subject of this article.

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Geriatrics Gerontology 1st Impact Factor in June 2010 Medline Indexed

Geriatr Gerontol Int 2011; **11:** *39–49*

ORIGINAL ARTICLE: EPIDEMIOLOGY, CLINICAL PRACTICE AND HEALTH

Spatiotemporal components of the 3-D gait analysis of community-dwelling middle-aged and elderly Japanese: Age- and sex-related differences

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Aim: To describe age- and sex-related differences in gait patterns of community-living men and women using 3-D gait analysis.

Methods: Subjects (n = 2006) aged 40–84 years participated in the National Institute for Longevity Sciences-Longitudinal Study of Aging (NILS-LSA). Spatiotemporal components, including velocity, step length, step frequency, and double support time during a gait cycle, were calculated from 3-D coordinates and vertical force data. Velocity, step length and step frequency were normalized by leg length and acceleration due to gravity, and double support time was normalized to gait cycle duration.

Results: Spatiotemporal walking variables of brisk velocity and step length were significantly greater in men than in women, while comfortable velocity and comfortable and brisk step frequencies and double support times were greater in women than in men. Age-related changes were marked at 70–84 years in most spatiotemporal variables in both sexes during comfortable walking. During brisk walking, age-related changes were observed from a younger age than during comfortable walking, and there were sex-related differences.

Conclusion: The age-related gait alteration was obvious among those aged 70 years and older, and it accelerated markedly in women's brisk walking intensity. **Geriatr Gerontol Int 2011; 11: 39–49.**

Keywords: aging, gait, sex, velocity, walking.

Accepted for publication 27 April 2010.

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Author contributions: W. D. designed the study, obtained the funding, analyzed data and drafted the original article; R. K. interpreted data and advised on revising the article; K. H. Y. supervised data processing and prepared the article; and F. A. and H. S. originated the study, created the gait analysis program, supervised all aspects of its implementations, and contributed to obtaining the funding and revising the article. All authors conducted epidemiological studies on geriatric disease and human aging in Obu, Aichi, Japan, and read and approved the manuscript.

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doi: 10.1111/j.1447-0594.2010.00632.x

Introduction

Age-related impairment of ambulatory ability is a critical component for inhibiting activities of daily living (ADL). For instance, decreased gait velocity observed in elderly is an indicator of common distinct diseases[1,2] and falls,[3–6] which lead to functional dependence[7–11] or death.[12] The prevalence and incidence of gait disorders increase with age in elderly persons.[13,14] The early presence of dynamic postural stability may provide more essential information for preserving adequate mobility, delaying the onset of functional decline and encouraging early appropriate lifestyle changes to promote active healthy aging.[6,8,10,11,15]

Previous studies examined age-related changes in spatiotemporal gait parameters including velocity, step length, step frequency (cadence) and selected stride time variables (single and double support time and swing time).[7,8,10,16–21] These performance-based gait variables were often measured by a 3-D gait system that computes the motions of the body center of mass (COM) and each segment, which can accurately evaluate the control of dynamic balance during walking.[22,23] The COM velocity on the 3-D gait system identified the effect of age on older gait in limited comparison between young and older groups.[24–26] It showed that the 3-D analyses conducted have not determined from which age group the accelerated decline of gait started. The collection of data using a large sample size with a broad age range could resolve the issue.

Age-related gait studies have recruited either men or women, or both sexes have been analyzed together: a few studies previously focused on sex-related changes on gait pattern with advancing age. Callisaya *et al.*[8] revealed the effects of sex and age on gait velocity in elderly men and women aged 60–86 years. The results of other studies of various age ranges and groups[17,19,27] to determine which sex shows an earlier age of accelerated gait velocity decrease have differed. The conflicts may partly depend on the sampling and subject characteristics.

Therefore, to understand the aging process in gait measures across the adult lifespan, a large sample size ranging from young or middle-aged to elderly men and women should be warranted. We decided to reinvestigate the previous findings. In the present study, the gait of elderly subjects was investigated based on comfortable and brisk spatiotemporal gait parameters with a 3-D gait analysis system; a large number of subjects were recruited. We found the age-related changes in gait by sex among middle-aged and elderly men and women in Japan. This may contribute to a beneficial effect on assessing gait in elderly people and making an adequate walking exercise program suitable for targeted age groups.

Methods

Study sampling

The present gait analysis is part of the third phase of the National Institute for Longevity Sciences Longitudinal Study of Aging (NILS-LSA); this study includes medical, physiological, nutritional and psychological examinations. The study began in November 1997 (the first phase), and the third phase lasted from May 2002 to May 2004. The subjects were age- and sex-stratified random samples of the population, aged 40–84 years, who lived in Obu-shi and Higashiura-cho, Aichi, Japan. These participants were chosen from the residents registered with local governments. All subjects lived or had lived at their home in the community and had Japanese nationality.[28] The NILS-LSA was approved by the Ethics Committee of the National Center for Geriatrics and Gerontology. Details of the NILS-LSA have been previously published.[28,29]

Of 2378 men and women aged 40–84 years in the third phase examination, 1017 men and 989 women (84.2% of all participants, Table 1) completed the walking tests and were included in the present analysis. The participants also completed a structured questionnaire dealing with their socioeconomic characteristics, cardiovascular risk factors and medical history.[28,29] Exclusion criteria included a current medical history of arthritis[6,8] and fractures (musculoskeletal disorders),[30] stroke[1] and Parkinson's disease (neurological disorders),[8,31] and ischemic heart disease and chronic bronchitis (Table 1).[32,33] These diseases were checked and excluded as the possible cause of gait disorders or spatiotemporal gait parameter changes by a physician before the walking tests. One participant who was diagnosed with dementia was excluded because she had a limited ability to comprehend or execute the test, which was judged by a physician. The existence of walking difficulty in activities of daily living (ADL)[11,15] was also excluded (Table 1). The participants who met the above-mentioned requirements and could walk 10 m independently without a walking aid were included in the current gait analysis and therefore 372 participants of the third phase examination were totally excluded.

Protocol

All participants wore short-sleeved T-shirts and shorts for testing. Shoes were made from the same material that had a vinylon/polyester and cotton blended upper part and a urethane foam outsole (Moonstar, Fukuoka, Japan), and were selected to exactly fit each participant's feet. Ten 2.5-cm diameter optical markers were placed on the participants' left and right sides on the fifth metatarsal heads, the lateral malleoli, the lateral epicondyles, and one-third of the way along the straight lines from the greater trochanters to the anterior

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Table 1 Inclusion/exclusion characteristics of 2378 participants in the third wave examination of the National Institute for Longevity Sciences-Longitudinal Study of Aging (NILS-LSA), 2002–2004

Characteristics	Men	Women
Inclusion (n = 2006)		
Total (n (%))	1017 (50.7)	989 (49.3)
Age group (n (%))†		
40s	250 (12.5)	279 (13.9)
50s	302 (15.1)	265 (13.2)
60s	250 (12.5)	242 (12.1)
≥70	215 (10.7)	203 (10.1)
Exclusion (n = 372)		
Total (n (%))	187 (50.3)	185 (49.7)
Prevalence of disease (n (%))		
Stroke	42 (22.5)	23 (12.4)
Ischemic heart disease	41 (21.9)	41 (22.2)
Chronic bronchitis	7 (3.7)	3 (1.6)
Arthritis	26 (13.9)	56 (30.3)
Fracture	5 (2.7)	6 (3.2)
Dementia	–	1 (0.5)
Parkinson's disease	3 (1.6)	–
Walking difficulties in ADL (n (%))	50 (26.7)	54 (29.2)
Not completed walking test (n (%))	55 (29.4)	53 (28.6)

†χ^2-Test test examines significance among each age group and sex. Values are numbers (% of total at each inclusion/exclusion category) of samples. ADL, activities of daily living.

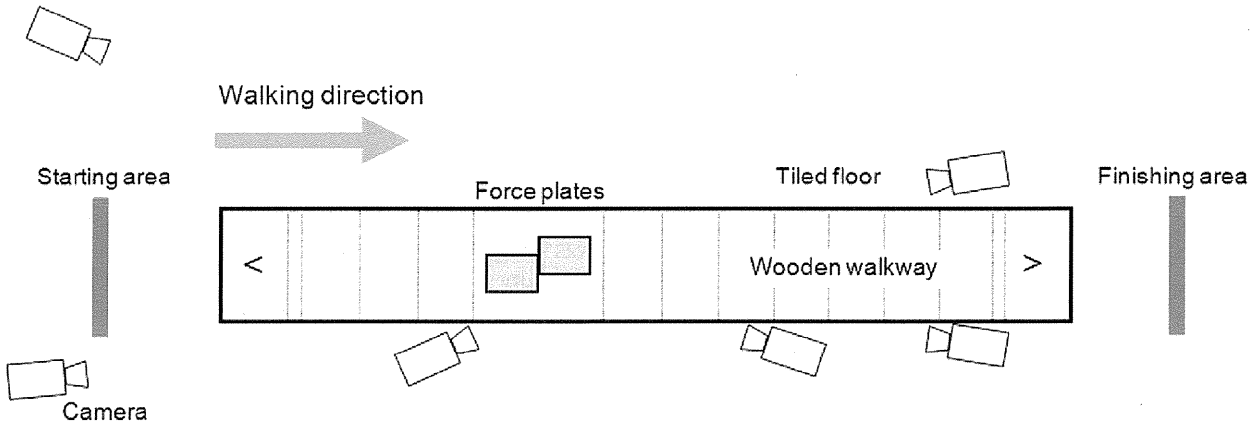

Figure 1 Setup of 3-D gait system: the 10-m walkway consisted of a wooden walkway. Six cameras were placed at various positions and two force platforms were embedded in the center of the walkway. Double support time in pre-swing phase of right foot was measured in this setting.

superior iliac spines and the acromions.[34] The subjects walked on a 10-m walkway at two speeds: (i) at a self-selected pace (comfortable walking); and (ii) as fast as possible without running (brisk walking). Each pace was repeated approximately twice on average. The walkway consisted of a tiled floor and a wooden walkway along the corridor (Fig. 1). The surface of the wooden walkway was covered with gray-colored, thin, stiff rubber, which measured 0.036 m in height from the tile floor surface of the corridor. Force platforms (0.6 m × 0.4 m) (9286; Kistler Instrumente AG, Winterthur, Switzerland), with surface colors similar to those of the walkways, were embedded in the center of the wooden walkway. The starting point for each trial was

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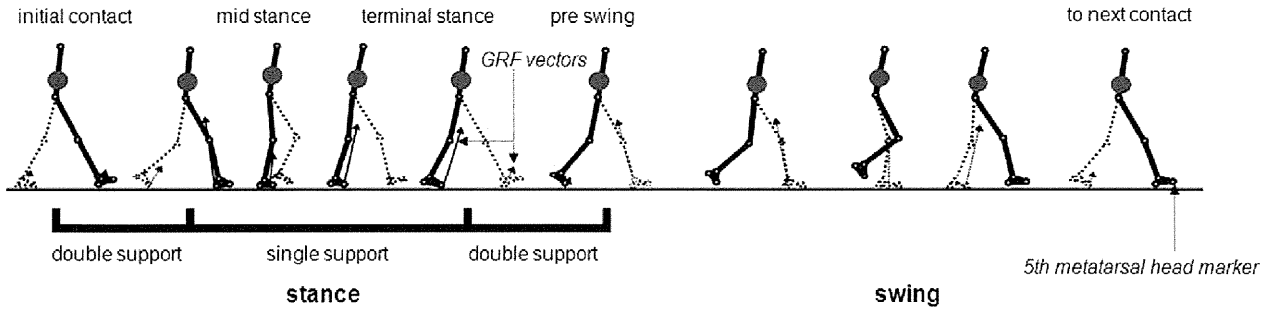

Figure 2 Definition of gait cycle using ground reaction force (GRF) and the fifth metatarsal head marker.

selected in relation to the foot contacts on the force platforms. The distance from each starting and departure point to the force platforms was approximately 3.5–4.5 m. One trial each of comfortable and brisk walking was used in the data analysis. The trials used were those that lacked the least data.

The Vicon 370 system (Oxford Metrics Ltd, Oxford, UK), which consisted of six cameras, was used to obtain the 3-D coordinates of the trunk, thighs, shins and feet. The calibration residual at each camera was set below 1.0 mm. The data were processed using a custom routine that was programmed by the Clinical Gait Analysis Forum of Japan.[34] The raw coordinate data at 60 Hz were digitally filtered with a fourth-order, zero-lag, Butterworth filter[22] with a cut-off at 5 Hz, and the raw ground reaction force data at 1200 Hz were digitally filtered with a cut-off at 10 Hz. The force data were interpolated to correspond with the coordinate data to synchronize the datasets. Smoothed coordinates of the lower extremities were used to construct a rigid link-segment model.[22] Segment masses and inertial properties were determined using previously reports[35] and the participants' mass and height, which were used for calculating COM.

Gait cycle and walking variable calculation

SAS ver. 9.1.3.[36] was used to automatically identify gait event times and each phase of the gait cycle based on kinematic and kinetic gait data. The divisions of the gait cycle are shown in Figure 2.[30] The gait event times for initial contacts and toe off were determined using vertical force data and the vertical motion of the optical marker on the fifth metatarsal head. The period from the first right initial contact to ipsilateral second initial contact was one gait cycle.[30]

Both the right and left leg motions were captured, and primarily the right stride was analyzed. Left leg motion was used for calculating the step length and double support times. The mean COM velocities, step lengths, step frequencies and double support times during a gait cycle were also automatically computed by SAS. The double support time was defined as the duration of time during which each foot was on the ground in the pre-swing phase. The mean COM velocity, step length, and step frequency were normalized as proposed by Hof[37] as follows:

$$\text{Normalized COM velocity, } \hat{v} = \frac{v}{\sqrt{gl_0}},$$

$$\text{Normalized step length, } \hat{l} = \frac{l}{l_0},$$

$$\text{Normalized step frequency, } \hat{f} = \frac{f}{\sqrt{g/l_0}},$$

where v is actual mean COM velocity, l_0 is the leg length of each subject, l is the actual step length, f is the actual step frequency and g is the acceleration due to gravity (9.81 m/s^2). Leg length was measured from the ground to the greater trochanter during quiet standing. Patients with arthritis and fracture were excluded (Table 1), and no case of limited knee extension was observed in the present study. The double support time was also normalized by each subject's cycle duration, from right initial contact to next right initial contact (over one gait cycle).

For the calculation of walking variables, technical difficulties sometimes caused missing data due to the effect of occlusion while capturing motion. Thus, for example, the mean COM velocity over the gait cycle was calculated using data from 1716 men and women (85.5% of the total sample) during comfortable walking and using data from 1614 men and women during brisk walking (80.4%). To demonstrate the lack (or presence) of bias with respect to velocity data loss, the Student's *t*-test was used to compare the velocity between the group with all available data and that with data available only in the velocity category. The results showed that the velocities were not significantly different between the two groups, and this was confirmed for all walking variables.

Statistical analyses

All analyses were performed using SAS ver. 9.1.3. Sex differences were examined using the Student's *t*-test. For analysis of age differences, participants were divided

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into eight groups based on sex and age (40–49, 50–59, 60–69 and 70–84 years for each sex). Trends in differences across all age groups in the walking variables were tested using the General Linear Model (GLM), and differences by age group were tested using the Tukey–Kramer method for each sex. $P < 0.05$ was considered statistically significant.

Results

The proportion of the sample drawn from each age group and each sex group was the same (χ^2-test, $P > 0.05$). The mean ± standard deviation age was 58.1 ± 11.4 years in men and 58.7 ± 11.4 years in women, which was not significant ($P > 0.05$).

The results of the GLM and Tukey–Kramer tests revealed age-related changes in each age and sex group. Descriptive statistics for all values are shown in Tables 2 and 3 and Figure 3. Mean COM velocities during comfortable and brisk walking significantly decreased with age in both sexes ($P < 0.001$). Age-related changes in the comfortable COM velocity were marked in the 70–84-year group compared with other age groups. Similar changes were found in the brisk COM velocity. The step lengths and frequencies followed these COM velocity patterns in both sexes during both comfortable and brisk walking.

These age-related changes occurred earlier in the middle-aged group. Earlier patterns involving brisk gait parameters were more apparent in women: for example, the brisk COM velocity decreased at 60–69 years in men and at 50–59 years in women, then the decrease accelerated at 70–84 years (Tables 2,3, Fig. 3). The step length and frequency followed these COM velocity patterns. The double support time during pre-swing was significantly increased with age only at the women's comfortable walking pace; it was significantly longer in the 70–84-year group compared to other age groups (Table 3, Fig. 3). The men's double support times showed no significant age-related differences among age groups (P for trend >0.05, Fig. 3).

Descriptive statistics and the results of sex differences for gait parameters are depicted in Table 4. The results of mean COM velocity differed according to walking pace: the comfortable COM velocity was significantly faster in women than in men ($P < 0.001$), and the brisk COM velocity was significantly faster in men than in women. Step length pattern was similar to COM velocity pattern: the brisk step length was longer in men than in women ($P < 0.001$), but the comfortable step length was not significantly different. On the other hand, women had a higher step frequency during both walking paces ($P < 0.001$). The results of the pre-swing double support time were equal to the step frequency.

Discussion

Mobility is essential for independence in the elderly. A better understanding of age-related changes in gait provides useful information for appropriate intervention programs targeting specific age groups.[8] The present cross-sectional, descriptive study showed spatiotemporal components of gait over one gait cycle among community-living middle-aged and elderly Japanese subjects. The sample of 1017 men and 989 women was large enough to allow analysis by age group,[17] and, to the best of our knowledge, the sample size is the largest to be published in which gait characteristics have been analyzed using a 3-D gait system. There was no disproportionate lack of gait data caused by difficulties in capturing the 3-D coordinates.

Mean COM velocities decreased with age, which is in almost complete agreement with previous results, despite the use of different measurement equipment and instrumentation.[16–21,25,29] The age-related decreases in the normalized COM velocities accelerated at 70 years and over were noted at a relatively later age compared with the previous reports: they showed the accelerated decline occurred in 50–59- and 60–69-year age groups,[17] at 62 years,[19] between 60- and 70-year age groups,[20] and at 65 years and in the 67–73-year age group.[18] The differences in age of accelerated decline among the previous and the present findings were likely due to the differences in method and data characteristics.

The brisk COM velocity decreases advancing with age were earlier compared with the comfortable walking. Some previous studies showed the age-related decrease was independent of walking pace,[18–20] while another reported that the decrease depended on the pace.[7] In a report by Bohannon on the comfortable and maximum walking speeds of adults aged 20–79 years,[7] walking speed was found to be influenced by the interaction of pace and age. This result matched our present findings that the age-related decrease was clearer during brisk walking than during comfortable walking. Moreover, these earlier age-related declines in the brisk COM velocities were apparent in women. Some studies reported that the critical age for marked velocity decrease did not differ by sex,[16,19] while another found the critical age to be earlier in men.[17] However, Callisaya *et al.*[8] showed women's walking velocity to be an earlier age-related change compared to men's parameters during the preferred speed of walking among the subjects aged 60 years and older. These results are in agreement with our own, though our data was particularly strong in the brisk parameters across middle-aged and elderly persons. The brisk walking task required greater forward momentum and increased demands in muscle activity[24,38–40] and aerobic capacity[33,41] might alter the spatiotemporal gait parameters accompanying aging.

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Table 2 Men's normalized mean COM velocities, step lengths and frequencies and double support times during comfortable and brisk walking in each age group

Men: walking parameters by age group	Mean COM velocity				Step length				Step frequency				Double support times (pre-swing)			
	N	Mean	SD	95% CI	N	Mean	SD	95% CI	N	Mean	SD	95% CI	N	Mean	SD	95% CI
Comfortable walking																
40s	211	0.524	0.053	0.517–0.531	240	0.892	0.065	0.884–0.900	207	0.587	0.043	0.582–0.593	208	14.8	1.5	14.6–15.0
50s	266	0.527	0.059	0.520–0.534	289	0.897	0.076	0.888–0.906	259	0.590	0.042	0.585–0.595	249	14.8	1.5	14.6–14.9
60s	218	0.523	0.067	0.514–0.532	240	0.901	0.089	0.890–0.913	215	0.583	0.046	0.577–0.589	205	14.5	1.6	14.3–14.7
70–	186	0.485	0.070	0.475–0.495	213	0.859	0.096	0.846–0.872	185	0.569	0.047	0.562–0.576	177	15.2	2.0	14.9–15.5
P for trend†	<0.001				<0.001				<0.001				NS			
(Tukey–Kramer test)‡	40s, 50s, 60s >70–				40s, 50s, 60s >70–				40s, 50s, 60s >70–				NA			
Brisk walking																
40s	190	0.705	0.078	0.694–0.716	229	0.998	0.074	0.989–1.008	180	0.707	0.070	0.696–0.717	173	13.3	6.0	12.4–14.2
50s	235	0.699	0.082	0.688–0.709	272	0.998	0.088	0.987–1.008	214	0.697	0.064	0.688–0.705	209	13.3	5.6	12.6–14.1
60s	191	0.678	0.079	0.667–0.690	237	1.000	0.094	0.988–1.012	185	0.685	0.066	0.676–0.695	180	13.4	5.0	12.6–14.1
70–	182	0.618	0.092	0.605–0.631	203	0.946	0.100	0.932–0.960	177	0.657	0.066	0.647–0.667	169	14.1	2.1	13.8–14.4
P for trend†	<0.001				<0.001				<0.001				NS			
(Tukey–Kramer test)‡	40s > 60s > 70–., 50s > 70–				40s, 50s, 60s >70–				40s > 60s > 70–., 50s > 70–				NA			

†Trend tests examine main effects of age in each gait parameter. ‡Tukey–Kramer tests examine the significant difference among each age group. '>' indicates the significant difference between the age groups, with *P*-value is less than 0.5. Values are numbers of samples (N), means (Mean), standard deviations (SD) and 95% confidence intervals (95% CI) at each variable. Age group: 40s, 40–49 years age group; 50s, 50–59 years age group; 60s, 60–69 years age group; 70–, 70–84 years age group. COM, center of mass; NS, not significant; NA, not applicable.

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Table 3 Women's normalized mean COM velocities, step lengths and frequencies and double support times during comfortable and brisk walking in each age group

Women: walking parameters by age group	Mean COM velocity				Step length				Step frequency				Double support times (pre-swing)			
	N	Mean	SD	95% CI	N	Mean	SD	95% CI	N	Mean	SD	95% CI	N	Mean	SD	95% CI
Comfortable walking																
40s	228	0.542	0.060	0.535–0.550	267	0.905	0.072	0.896–0.913	223	0.602	0.044	0.596–0.608	212	14.9	1.7	14.7–15.2
50s	224	0.547	0.066	0.538–0.556	252	0.902	0.082	0.891–0.912	219	0.607	0.051	0.600–0.614	214	14.9	1.7	14.7–15.1
60s	210	0.536	0.064	0.527–0.544	236	0.890	0.079	0.880–0.900	207	0.602	0.045	0.596–0.608	189	15.0	1.9	14.8–15.3
70–	173	0.472	0.071	0.461–0.483	189	0.833	0.093	0.820–0.847	169	0.570	0.051	0.562–0.578	148	15.8	1.9	15.5–16.1
P for trend†	<0.001				<0.001				<0.001				<0.001			
(Tukey–Kramer test)‡	40s, 50s, 60s >70–				40s, 50s, 60s >70–				40s, 50s, 60s >70–				70– > 60s, 50s, 40s			
Brisk walking																
40s	216	0.702	0.072	0.692–0.711	269	0.972	0.070	0.963–0.980	210	0.728	0.071	0.719–0.738	201	13.9	1.6	13.7–14.2
50s	215	0.675	0.080	0.665–0.686	252	0.960	0.087	0.950–0.971	212	0.706	0.073	0.696–0.715	209	14.2	1.7	13.9–14.4
60s	212	0.653	0.072	0.643–0.662	230	0.941	0.085	0.929–0.952	209	0.696	0.072	0.687–0.706	199	14.2	1.8	14.0–14.5
70–	173	0.577	0.084	0.565–0.590	187	0.890	0.109	0.875–0.906	163	0.651	0.064	0.562–0.578	157	14.3	8.8	12.9–15.7
P for trend‡	<0.001				<0.001				<0.001				NS			
(Tukey–Kramer test)‡	40s > 50s > 60s > 70–				40s > 60s > 70–., 50s > 70–				40s > 50s, 60s > 70–				NA			

†Trend tests examine main effects of age in each gait parameter. ‡Tukey–Kramer tests examine the significant difference among each age group. '>' indicates the significant difference between the age groups, with $P < 0.05$. Values are numbers of samples (N), means, standard deviations (SD) and 95% confidence intervals (95% CI) at each variable. Age group: 40s, 40–49 years age group; 50s, 50–59 years age group; 60s, 60–69 years age group; 70–, 70–84 years age group. COM, center of mass; NS, not significant; NA, not applicable.

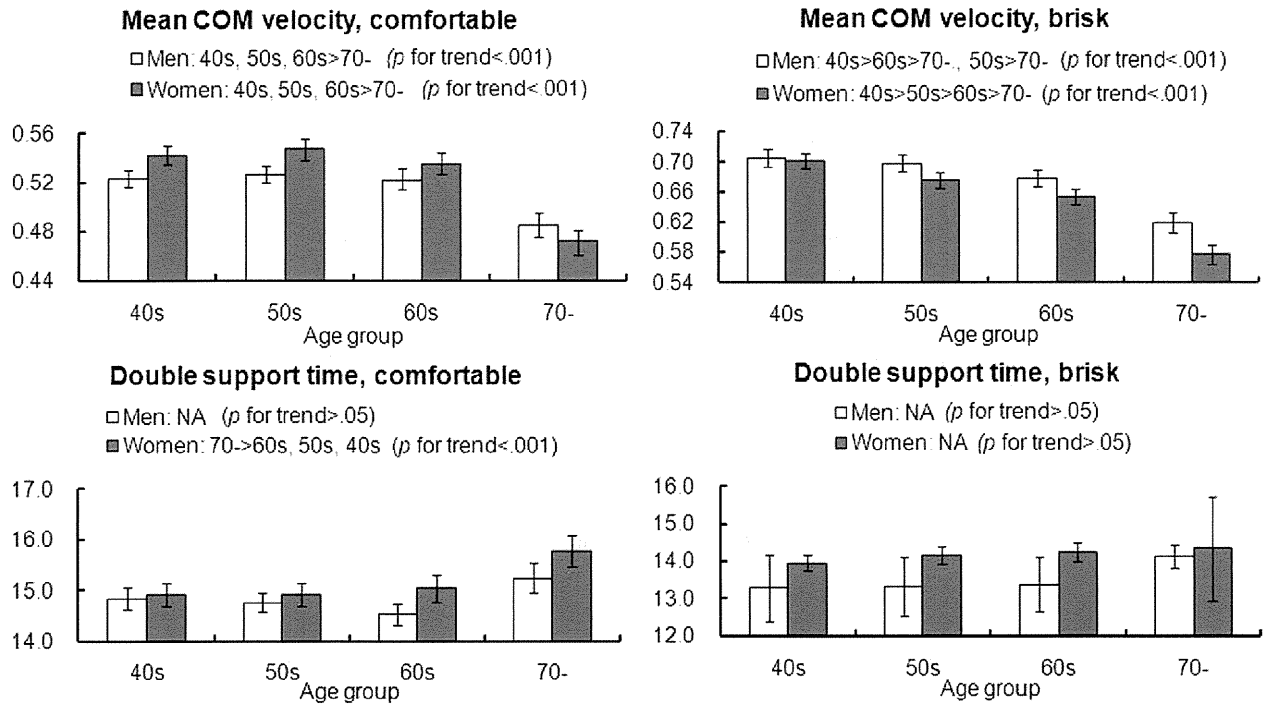

Figure 3 Age-related differences (trend tests and Tukey–Kramer tests); means and 95% confidence intervals of normalized mean center of mass (COM) velocities ($(m/sec)/\sqrt{((m/sec^2)\times m)}$) and double support times (s/s) during comfortable and brisk walking in men and women. Significant differences by age group in men and women are noted on the upper side of each figure. '>' indicates the significant difference between the age groups, with *P*-values of ≤0.05.

Table 4 Normalized mean COM velocities, step lengths and frequencies and double support times during comfortable and brisk walking among men and women

Walking parameters	Men				Women				*P*-value†
	N	Mean	SD	95% CI	N	Mean	SD	95% CI	
Comfortable walking									
Mean COM velocity	881	0.516	0.064	0.512–0.521	835	0.527	0.071	0.523–0.532	<0.001
Step length	982	0.889	0.083	0.883–0.894	944	0.886	0.085	0.881–0.891	NS
Step frequency	866	0.583	0.069	0.580–0.586	818	0.597	0.045	0.593–0.600	<0.001
Double support time (pre-swing)	839	14.8	1.7	14.7–14.9	763	15.1	1.8	15.0–15.2	<0.001
Brisk walking									
Mean COM velocity	798	0.677	0.089	0.671–0.683	816	0.656	0.089	0.650–0.662	<0.001
Step length	941	0.987	0.092	0.981–0.993	938	0.945	0.092	0.939–0.951	<0.001
Step frequency	756	0.687	0.075	0.682–0.692	794	0.698	0.049	0.693–0.703	<0.001
Double support time (pre-swing)	731	13.5	5.0	13.2–13.9	766	14.2	4.3	13.9–14.5	<0.01

†Student *t*-tests examine the sex differences. Values are numbers of samples (N), means, standard deviations (SD) and 95% confidence intervals (95% CI) at each variable. COM, center of mass; NS, not significant.

Further investigation should have discussed the difference between comfortable and brisk walking parameters.[38,42,43]

Age-related step length decreases during comfortable and brisk walking were almost concomitant with the COM velocity decreases, which was similar to the previous findings.[16,20] In brisk walking, however, age-related reduction in the step length seemed to be smaller than that in the step frequency compared with comfortable walking. For example, women's brisk step length decrease was 8.4% across middle-aged and elderly groups compared with their step frequency decrease of 10.7% (Table 3). This was observed also in men's. This may suggest that ambulatory ability observed in the COM velocity may be caused more by the step length during comfortable walking and the step frequency

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during brisk walking in the elderly. This was also apparent in middle-aged women. The interpretation was limited qualitatively and should be further explored.

Step frequencies also decreased with age and this decrease was found even in middle-aged women during brisk walking. Previous studies in step frequency reported no age-related changes,[16,17,21] age-related decrease[8,18–20,25] and age-related increase.[26] Moreover, the current age- and sex-related decrease depending on required walking pace was not previously reported.[16,17] One explanation of these conflicts was that degree of the age-related reduction in step frequency was relatively less than that in other gait parameters such as velocity or step length.[8,17,19,20] Therefore, sample size, subject characteristics and measuring instruments may affect the age-related decrease in the step frequency.[16,25] Double support times in the present study did not increase with age, with the exception of women's comfortable data. On the other hand, exploratory analyses of actual values of double support times showed age-related increases in both sexes during both walking paces (data not shown, P for trend <0.001, <0.022). This shows that the double support as a percentage of one gait cycle remained almost constant in middle-aged and elderly subjects. Ferrandez *et al.*[32] found that double support time increased as velocity decreased, and that prolonged double support time was affected more by walking velocity than age.

The present study found brisk COM velocity and step length to be greater in men than in women. By contrast, step frequencies and double support times were greater in women than in men. This is characteristic of sex differences and is supported by previous findings.[8,17,21] Although the comfortable COM velocity was faster in women than in men, this is believed to be a result of the difference in body size as the actual comfortable COM velocity was significantly faster in men than in women (men, 1.46 ± 0.18 m/s; women, 1.43 ± 0.20 m/s; $P < 0.001$). The comfortable step length did not differ significantly between either sex group, perhaps because of the slower men's COM velocity.

The present gait data may give some insight into gait assessment and preventive walking exercise programs for older persons as previously reported.[42,44,45] The values for the gait parameters during one gait cycle may be useful to clinicians judging the ambulatory ability of patients from a short indoor walk.[7,42] Patients whose gait parameters are lower than that of their appropriate age group are at increased risk of ADL difficulties.[8,11] Comfortable and brisk walking velocities are predictive of adverse outcomes such as loss of physical function, requirement of caregivers, hospitalization and increased mortality in elderly persons.[8,10–12] Decreased step length and prolonged double support time are correlated with fear of falling and/or future fall risk.[4,5,9] Also, the other gait parameters such as gait velocity,[9,11] stride-to-stride variability[4] and lateral sway[3,5,6,46] are associated with the falling events. We did not directly ascertain whether the participants had a history of falls and/or a fear of falling in our gait parameters. Further work should confirm which gait measure is the best independent predictor for future fall risk in a large sample.

A moderate workload prescription in walking exercise programs should be given by controlling both step length and step frequency during comfortable walking in the elderly. Brisk walking, which is recommended for moderately vigorous endurance training and has a high impact compared to comfortable pace walking, might be considered for middle-aged women and the elderly to improve physical functions such as muscle strength[7,40,43] and/or cardiovascular fitness.[33,41]

This study has some limitations. Some previous gait investigations used the results of several trials or mean values of gait, while we used gait data from one trial of each participant. This was done because of technical difficulties in the automatically computed 3-D gait parameters. Next, the conjunction of our excluding criteria with the potential diseases might overestimate gait disorders: the elderly subjects were more likely to be healthy and physically fit. Moreover, patients with dementia were considered to be less in the present sample. The general comparability of the present gait variables with previously reported data is limited because of the lack of data for young adults in their 20s and 30s. Furthermore, our cross-sectional analysis approach could not demonstrate a cause-and-effect relationship from aging. We are planning longitudinal studies to further determine the effects of aging on gait. The present study included regional limitations such as race, culture, lifestyle, genetics and socioeconomic status which also may be important. However, the findings did permit age- and sex-related differences in gait to be clarified in the elderly.

In conclusion, age- and sex-related gait alterations were apparent in one gait cycle of walking in a large sample of community-dwelling, middle-aged and elderly Japanese men and women, when analyzed by a 3-D gait system. There were marked age-related gait differences in subjects aged 70 years and over compared to subjects aged 40–69 years during comfortable walking, and subtle differences were also observed in subjects aged 40–69 years during brisk walking. The earlier age-related changes were clearer in women than in men. These results may guide the assessment of gait patterns attributed to usual aging and to develop moderate exercise programs for the elderly.

Acknowledgments

The authors would like to thank the participants and their colleagues involved in the NILS-LSA. This study

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was supported by a Grant-in-Aid for Exploratory Research from the Ministry of Education, Culture, Sports, Science and Technology of Japan (no. 18650203).

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