Original article

Diagnosis of knee osteoarthritis and gait variability increases risk of falling for osteoporotic older adults: The GAINA study

Hiromi Matsumoto a,*, Hiroshi Hagino a, Hirofumi Sageshima a, Mari Osaki a, Shinji Tanishima c, Chika Tanimura b

a Rehabilitation Division, Tottori University Hospital, Nishicho 36-1, Yonago, Tottori 683-8504, Japan
b School of Health Science, Faculty of Medicine, Tottori University, Nishicho 86, Yonago, Tottori 683-8503, Japan
c Orthopedic Surgery, Tottori University Hospital, Nishicho 36-1, Yonago, Tottori 683-8504, Japan

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Abstract

Objectives: To examine the relationship between history of falling, and musculoskeletal disease, bone mass, muscle strength, muscle mass, kyphosis, and gait speed and variability in osteoporotic older adults.

Methods: The GAINA study, which began in 2014, is a population-based prospective study of subject cohorts from the town of Hino, Tottori Prefecture, Japan. Participants were recruited from among individuals who had an annual town-sponsored medical check-up in 2014, between May and June. A total 223 of residents were screened for our study. Inclusion criteria were osteoporotic older adults who had: (1) a ≤70% young adult mean (YAM) bone mass as assessed using quantitative ultrasound (QUS) methods, (2) a prior hip fracture or vertebral fracture, (3) fragility fractures other than hip and vertebral fractures and <80% YAM of bone mass. From the total screened, 91 residents (mean age, 76.0 ± 8.0 years; 22 men and 69 women) met the eligibility criteria. History of falling, diagnosis of musculoskeletal disease, bone mass, grip strength, muscle mass, kyphosis, and gait speed were assessed. Gait variability analysis was based on acceleration in three directions: mediolateral (ML), vertical (VT), and anteroposterior (AP) using a wireless triaxial accelerometer. Subjects were classified as belonging to a nonfall group or fall group based on their history of falling.

Results: During the previous 12 months, 26 falls were reported by 16 subjects (5 men and 11 women). Sixteen of the 91 included patients (17.6%) fell (22% men and 15% women), and 8 of the 16 subjects reported multiple falls. In a multivariable analysis, diagnosis of knee osteoarthritis and higher gait variability had a significant independent relationship with falling in these osteoporotic adults.

Conclusions: Diagnosis of knee osteoarthritis and gait variability are associated with previous falls in osteoporotic older adults. Accelerometry-based gait analysis may be a useful tool with which to assess the risk of falling in this population.

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Keywords: Osteoporosis; Falling; Knee osteoarthritis; Gait variability

1. Introduction

The risk of fractures in osteoporotic older adults is higher than in those without osteoporosis as a result of increased bone fragility. Osteoporosis, characterized by low bone mineral density (BMD) and previous fragility fractures, is a common condition in older adults [1,2], and a major public health problem leading to lower quality of life, functional decline, and death [3]. The estimated number of Japanese people over 40 years old with L2–L4 and femoral neck osteoporosis is approximately 17.4 million [4]. Patients with prior hip fractures are at a 3-fold higher risk of a subsequent fracture, and those hospitalized with other nonhip fractures are at a 1.8 higher risk of a subsequent fracture [5]. It is important to
prevent such osteoporotic older adults from falling, because over 80% of incident fractures are associated with falls [6,7] and this proportion increases after 60 years of age [8,9]. Thus, assessment of risk factors for falls in older adults with osteoporosis is necessary to avoid fractures associated with advancing ageing.

Kyphosis is a risk factor for falls in these individuals [10]. Dysfunction of static standing postural controls also exists in patients with osteoporosis [11]. However, these conditions may insufficiently clarify the risk of falling in these individuals, because osteoporosis related factors are not only kyphosis, but lower muscles mass [12], muscle strength [13], lower gait speed and gait variability [14], all of which are aging phenomena and fall-related risk factors. We propose that these intrinsic fall-related factors associated with osteoporosis should be analyzed to assess the risk of falls in older individuals.

Theoretically, variables such as musculoskeletal disease, muscle strength, muscle mass kyphosis, and gait speed and variability may have an impact on the risk of falling in patients with osteoporosis. By identifying the intrinsic factors for increased risk of falls, appropriate screening tests and tailored interventions may be developed for this population at high risk for fractures. The purpose of this study was to examine the relationship between history of falling, and musculoskeletal disease, bone mass, muscle strength, muscle mass kyphosis, and gait speed and variability in osteoporotic older adults.

2. Methods

2.1. Subjects

This study was based on results obtained from a cohort study of participants who enrolled in the Good Aging and Intervention for against Nursing care and Activity decline (GAINA) study. This study, which began in 2014, is a population-based prospective study of residents from the town of Hino, Tottori Prefecture, Japan. A flow chart of the population-based prospective study of residents from the GAINA study. This study, which began in 2014, is a Intervention for against Nursing care and Activity decline 2.1. Subjects 2.2. Methods

2.2. Measurements

2.2.1. Demographic information

Demographic information such as age, sex, height, weight, and body mass index (BMI), as well as any diagnosis of hypertension, diabetes mellitus, cardiovascular diseases, and/or cerebrovascular diseases were recorded at the time of the medical check-up. A self-administered questionnaire was provided to the subjects to gather information about their possible use of hypnotic pills, diuretic pills, and steroid medications, and to document any treatment received for osteoporosis, previous diagnosis/history of osteoarthritis (OA) of the knee, OA of the hip, spinal canal stenosis, lumbar spondylosis, rheumatoid arthritis, and pain at the knee and/or lumbar spine using a visual analog scale (VAS). The results of the self-administered questionnaire were then checked for accuracy by researchers in a face-to-face interview with each subject.

2.2.2. Bone mass

QUS was used to assess calcaneal bone mass. The speed of sound through the calcaneus bone was measured using a CM-200 sonometer (Furuno Co, Nishinomiya City, Japan). QUS is not directly comparable with the criterion standard dual-energy X-ray absorption (DXA) scan, but is able to discriminate the risk of fractures in older adults [16]. Advantages are that the device is portable and does not use ionizing radiation. The subject was seated and placed their right heel on the QUS device. Coupling gel was applied to each subject's right heel to facilitate the transmission of ultrasound to the examined skeletal site. %YAM was calculated on calcaneal speed of sounds.

2.2.3. Fall assessment

Subjects were asked about fall frequency, injuries because of falling, and fracture because of falling in the 12 months before the questionnaire. A fall was defined as unintentionally coming down to the ground or other lower level without being the result of a major intrinsic event such as a seizure, fainting, or stroke [17]. Subjects were divided into 2 groups based on their self-reported fall history: the nonfall group (no fall) and fall group (one or more falls).

2.2.4. Muscle strength

Lower handgrip strength indicates frailty and disability [18]. Handgrip strength was measured using a T.K.K 5401 dynamometer (Takei Co, Niigata, Japan). The subjects were asked to squeeze the dynamometer twice with each hand in a standing position with arms held parallel to the body. The highest scores for the left and right hands were summed.

2.2.5. Muscle mass

Lower muscle mass is associated with falling [19]. Muscle mass was measured by Bioelectrical Impedance Analysis (BIA) using a MC-780A Body Composition Analyser (Tanita Co, Tokyo, Japan). BIA measures the impedance or resistance to the signal as it travels through the water that is present in
muscle and fat. The BIA method requires subjects to step onto a platform that looks similar to a bathroom scale, and they remain in a standing position for approximately 30 s. Electrodes in the foot sensor pads send a low current through the body, which is considered safe. Muscle mass index was calculated by dividing total muscle mass by height in meters squared (kg/m²).

2.2.6. Kyphosis

Kyphosis is associated with an increased risk of falls [20]. We assessed kyphosis using a method described by Takahashi [21]. Subjects had reflective surface markers attached to their body at various locations, including at C7, T6, L4, the left greater trochanter, the left lateral condyle of the femur, and the left lateral. For the photograph, participants were carefully positioned and asked to remain relaxed while standing up straight. Posture was classified into three types: (1) thoracic hyperkyphosis, (2) lumbar kyphosis, and (3) normal or excluding (1) or (2). We defined (1) and (2) as kyphotic posture. Three physical therapists independently determined the classification, and we adopted the classification with consensus from at least two of the therapists.

2.2.7. Gait speed and step length

Gait parameters were assessed with the Opto Gait (Microgate Co, Bolzano, Italy). The Opto Gait is a 3-m walkway designed for optical-sensitive analysis. The subjects completed a single trial at free speed with the instruction to “walk at your normal speed.” Individually determined rest periods were provided between single trials undertaken. Gait speed and mean step length were calculated using specific software (Opto Gait analysis software, version 1.6.4.0).

2.2.8. Gait variability

We assessed gait variability using a small (45 mm × 45 mm × 18.5 mm) triaxial accelerometer MVP-RF8 (Micro Stone Co, Nagano, Japan). Subjects were instructed to walk at a pace they considered normal speed. Measurements were performed over the middle (5 m) of the total distance covered (9 m), and the first and last 2 m were excluded to eliminate periods of acceleration and deceleration. Researchers attached the accelerometer to the subject’s L3 spinous process with a belt that did not restrict the participant’s movements. Linear accelerations of the trunk were measured along the three axes: mediolateral (ML), vertical (VT), and anteroposterior (AP), at 200 Hz. After testing, a data logger was connected to a computer and the raw data were downloaded into a database for later analysis off-line. We used auto correlation (AC) methods for analysis of gait variability [22,23]. AC is a method used to analyze the sequence of a domain signal, such as the time, in signal processing [23]. We analyzed AC using the acceleration waveform during the 5 m at normal gait speed. AC represents the correlation coefficient when the acceleration signal is shifted by the mean step time from the original signal. A perfect replication of the gait cycle signal between neighboring strides will return an AC of 1, and no association will yield a coefficient of 0.

2.3. Statistical analysis

All data are expressed as mean ± SD. Differences between nonfall and fall groups were determined using Pearson’s chi-square test to compare nominal scaling. An unpaired t test was used to compare continuous variables between the nonfall and fall groups.

Variables with P < 0.1 in the univariate analysis were selected for the multivariable model. Multiple logistic
regression was used to obtain simultaneous estimates of adjusted odds ratios for associations with falling. All data were analyzed using SPSS statistical software (version 22 for Windows; IBM Co, Tokyo). $P < 0.05$ was considered significant.

3. Results

3.1. Demographic information

Characteristics of participants in the nonfall and fall groups are presented in Table 1. For the demographic characteristics evaluated, only diagnosis of knee OA was significantly different between nonfall and fall groups. Spinal canal stenosis was greater in the fall group than in the nonfall group. Differences in other variables were not significant.

3.2. Numbers of falls and fractures

During the previous 12 months, 26 falls were reported by 16 subjects (5 men and 11 women). Sixteen of 91 patients fell (17.6%; 22% men and 15% women), and 8 of the 16 subjects reported multiple falls. Four fractures occurred in fallers because of falling: 2 upper arm fractures and 2 hip fractures.

3.3. Body function and structures

Body function and structure measurements of the nonfall and fall groups are presented in Table 2. The AC–AP analyzed accelerometer values had a significant independent relationship with falling in the osteoporotic older adults in the multivariable analysis (odds ratio 3.765, 95% CI 1.044–13.582, $P = 0.043$; odds ratio 0.957, 95% CI 0.919–0.998, $P = 0.039$, respectively) (Table 3).

4. Discussion

Our investigation showed that 16 of the 91 older adults with osteoporosis fell at least once during the previous 12 months. The prevalence of falls was 17.6%, which was consistent with a previously reported prevalence range of about 10%–20% among healthy older adults in Japan [24]. In a previous study to examine the relationship between a history of recent falls and motor function in postmenopausal women with osteoporosis, 22 of the 73 women questioned (30%) had fallen in the past 6 months. Similarly, in another study 30% of women in early postmenopause with low BMD fell in the 12-month follow-up period [14]. Surprisingly, 50% of women with osteoporosis had fallen at least once in the previous 12 months [25]. There was higher rate of falling compared with that found in our study (of participants with mean age 76 years) despite the subjects in previous studies being of lower mean age (68 years, 59 years, and 66 years, respectively). Fall rate among the older adults in the general Japanese population is lower than in Europeans and Americans [24]. Generally, the rate of falling by men is less than that in women in the general population [24], although the rate of falling by men in the present study is a few higher percentage points higher than in women. Our sample was of healthy older adult participants.
who did not have long-term care insurance and underwent a town-sponsored medical check-up. Thus, it is possible our subjects are not as likely to fall compared with those in previous studies where subjects had a different background.

Fall-related factors among osteoporotic older adults have shown a relationship between falling and the degree of kyphosis and spinal dysfunction because of osteoporosis [10, 25]. Hyperkyphotic posture may be an easily identifiable independent risk factor for falls in the general population [20]. Increased thoracic kyphosis has intrinsic factors associated with falling in postmenopausal women with osteoporosis [10]. Abnormal spinal alignment is related to falling through a decrease in standing balance, because kyphosis shifts the center of gravity from a normal neutral position on standing. By contrast, the prevalence of kyphosis was not significantly related to falls among the participants in our study. Subjects classified as kyphosis in all our samples were only 23.1% compared to 77% in a previous study [10]. Our subjects may be healthier older adults than in the previous study and had not progressed to osteoporotic related comorbidities such as kyphosis. Therefore, kyphosis could not be correlated with falling for the individuals in this study. Another study showed that osteoporosis was associated with a postural balance defect assessed by posturography more than was hyper kyphosis compared to controls [11,26]. Thus, we suggest that the data in this study may be insufficient to clarify the relationship between kyphosis and incidence of falling among the individuals. Additionally, we speculated that static alignment dysfunction alone was not an independent risk factor for falling among these individuals because falling is related to multiple factors and loss of dynamic balance rather than static balance.

The present study indicated knee OA is associated with previous falling in osteoporotic older adults. Prevalence of knee OA is a common risk of falling in the general population [27]. Additionally, patients with a clinical diagnosis of knee OA have a greater risk of all nonvertebral and hip fractures than patients with knee pain alone [28]. We initially speculated that pain because of knee OA was related to falling, because these are common risk factors for falling in older adults in general [29]. We infer that the prevalence of knee pain due to knee OA was higher in the fall group if our assessment was performed only for knee pain; VAS assessment was combined with screening for pain at the knee and/or lumbar spine in our study. Second, generally, individuals with knee OA have greater coefficients of variation in step length, step width, and double support time, proprioceptive impairment, and consistency of movement, because dysfunction in lower leg abnormal alignment increases risk of falling [30]. In general, there is an inverse relationship between OA and osteoporosis, whereas it commonly occurs in the setting of inflammatory arthritis [31]. This is somewhat paradoxical considering individuals with OA have increased bone mineral density compared with controls, and that increased BMD is generally considered to confer protection from fractures [31]. However, the increase in fracture risk is due to the increased incidence of falls and/or an increase in the severity of falls. Our study suggested that knee OA is a risk factor of falling regardless of the presence of osteoporosis among older adults because it does not seem to decrease in older adults with OA despite having a high or lower BMD. This is probably due to postural instability and decreased muscle strength among OA patients. Therefore, older adults who had both osteoporosis and knee OA had a higher risk for falling and fractures due to their respective physical defects and lower BMD [32,33].

Gait variability in the AP direction based on accelerometry analysis was also an independent risk factor for falling in the participants in the present study. Gait variability conceptually links increased movement variability with decreased neuromuscular control, and this has an important relationship with falling [22,34]. To our knowledge, only one previous study showed an association with gait variability and osteoporosis [14]. This previous study showed that women with low BMD exhibited increased gait variability in step time and stance time, but did not exhibit differences in balance, strength, or gait speed. They suggested that gait variability may be more sensitive for detecting differences in women with or without low BMD than other typical physical performance tests. By contrast, force platform studies showed that older adults with osteoporosis had a decline of postural control rather than kyphosis postural alignment [11,26], and higher Center of Pressure (COP) displacement and velocity in the AP direction was found in patients with osteoporosis compared with controls, although there were no differences between groups when comparison was based on the magnitude of thoracic kyphosis [35]. We speculated that several factors related to osteoporosis, namely age, frailty, and aging-related disease such as knee OA, cause gait variability and are related to the loss of dynamic and/or static standing postural control rather than kyphosis, and may be related to falling in these individuals.

Previous studies investigating risk factors for falling among several groups of patients have shown that gait

<table>
<thead>
<tr>
<th>Predictor</th>
<th>B</th>
<th>Wald</th>
<th>95%CI</th>
<th>Odds ratio</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Osteoarthritis of the knee</td>
<td>1.326</td>
<td>4.103</td>
<td>1.044</td>
<td>13.582</td>
<td>3.765</td>
</tr>
<tr>
<td>Spinal canal stenosis</td>
<td>2.019</td>
<td>3.311</td>
<td>0.856</td>
<td>66.298</td>
<td>7.532</td>
</tr>
<tr>
<td>Gait variability analyzed using a accelerometer</td>
<td>−0.0435</td>
<td>4.269</td>
<td>0.919</td>
<td>0.998</td>
<td>0.957</td>
</tr>
</tbody>
</table>

AC-AP: Autocorrelation anteroposterior axes.
analysis with accelerometry may be superior to other performance tests including TUG, 5-times sit-to-stand, gait speed, one-leg standing test, and functional reach [34,36–39]. Functional performance tests did not show significant differences in postural control for osteoporotic patients compared with controls [40]. Thus, functional performance tests are less sensitive than computerized tests in the osteoporotic population. Additionally, accelerometry data can be used to comprehensively evaluate motor function, including lower extremity muscle strength, standing balance, and gait speed. Gait analysis with an accelerometer may also identify the risk of falling in these individuals.

Our study has several limitations. First, we did not assess BMD using the criterion standard DXA measurement for osteoporosis. Thus, there is the possibility of selection bias. However, QUS techniques in fracture risk prediction have been proven, and with their recent developments have made them a more reliable approach for assessing bone quality. Second, this study was an assessment of falls and diagnosis of knee OA based upon self-reports. This might have influenced the estimation of their prevalence, although we checked for accuracy through face-to-face interview with each subject. Third, in this study we could not objectively assess kyphosis. To confirm our findings further prospective studies should assess the relationship between risk of falling and kyphosis using objective methods. Fourth, this study was a cross-sectional design that showed clear associations between prevalence of falling, gait variability and knee OA. Further prospective studies will need to better clarify causal inferences between these variables.

In conclusion, we found that knee OA and higher gait variability are associated with previous falling in osteoporotic older adults. We suggest that interventions for knee OA and gait variability could be used to reduce falling and fracture among the patients with osteoporosis, and accelerometry-based gait analysis may be a useful tool for assessing the risk of falling in this population.

Conflict of interest

This study was supported by a Ministry of Education, Culture, Sports, Science and Technology Grant (Chino kyoten seibi jigyō) and a Grant-in-Aid from Japanese Society for Musculoskeletal Medicine.

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