A Preliminary Study of Static and Dynamic Standing Balance and Risk of Falling in an Independent Elderly Population with a Particular Focus on the Limit of Stability Test

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Abstract. [Purpose] The purpose of this study was to evaluate the balance ability of older adults from many points of view, and to evaluate fall risk. The effects of various parameters on the frequency of falls were also investigated using discriminant analysis. [Subjects and Methods] Subjects were 79 elderly (73.2 ± 4.2 yrs) with no serious disease living independently at home and 70 healthy young adults (20.7 ± 1.4 yrs). We conducted a posturographic evaluation, a two-point discrimination of pressure sensation at the plantar sole, measured grip strength and range of motion of the lower extremities, and conducted a clinical balance test (Berg Balance Test). [Results] The following relationship was obtained: Z (discriminant function) = 0.002×the total value of the Limit of Stability test + 0.139×Grip Strength –4.15. Moreover, the female group showed a significantly higher fall rate than the male group, and had a higher center of pressure speed than the male group. [Conclusion] Total score of the limit of stability test and grip strength were related to the frequency of falls, suggesting that these parameters may be useful in screening for falls.

Key words: Fall, Limit of stability, Balance

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INTRODUCTION

According to the Ministry of Internal Affairs and Communications’ 2008 demographic survey, 21% of the population of Japan is over 65 years old, and this proportion is expected to increase further1). The Ministry of Health, Labour and Welfare’s demographic survey, states that the number of accidental deaths in the home amongst Japanese over 65-year-olds was 9,421 in 2006, of which about 20% were due to stumbles and falls2). These figures are about 20% higher than those for 1997. Amongst over 65-year-olds, 1/3 have experienced one fall or repeated falls3). Consequently, we believe that the issue of preventing falls amongst the elderly will be an extremely important one.

Elderly women have greater decreases in motor function than elderly men4) and a higher prevalence of osteoporosis5); therefore, they are at higher risk of falls and fractures. Accordingly, evaluation of motor function in relation to gender is necessary in the development of measures to prevent falls.

Postural control needs to integrate visual, vestibular and somatosensory inputs with the musculoskeletal system. However, there are many differences between young and elderly people in this postural control system. Declines in balance ability are related to age-related loss of muscular strength in the lower limbs, increased sensory thresholds due to sensory organ degeneration, extended muscular reaction latency, and errors in motor strategy selection. Tanaka et al. reported that, in the context of the relationship between sensation in the toes and balance ability, a group of elderly people exhibited a significantly higher sensation threshold for displacement of the toe, than a young group, and pointed out the importance of tactile sensation in the toes and soles in balance ability5). Horak et al. reported changes in strategies from the ankle to the hip, due to ankle function decline in an elderly group6). A relationship between clinical tests such as the Berg Balance Scale and falls has also been reported7). In a detailed evaluation of balance ability of the elderly, a quantitative investigation of balance together with a collection of the physical data described above, as well as observations of motor strategies is necessary.

The aim of this study was to obtain findings on fall risk from a wide-ranging analysis of static and dynamic balance ability of elderly people. The effects of various parameters including gender on the frequency of falls was also
investigated using statistical methods.

SUBJECTS AND METHODS

Subjects were 79 elderly adults (29 males and 50 females; age 73.2 ± 4.2 yrs; height: 156.9 ± 6.7 cm; weight: 56.0 ± 8.2 kg) who lived independently at home and had no serious diseases. They were recruited through a newspaper notice. In addition, 70 healthy young adults (20 males and 50 females; age 20.7 ± 1.4 yrs; height: 163.5 ± 1.4 cm; weight: 62.1 ± 12.8 kg) participated in the study. This research obtained approval from the Ethics Committee of Sapporo City University and all subjects submitted their written informed consent.

Basic body function data (height, weight, dominant hand and foot) was collected and a clinical balance test (Berg Balance Scale) was performed by the subjects. Subjects in the elderly group were asked to complete a questionnaire recording their experience of falls within the past year.

Subjects in the elderly group took the lower extremity muscle strength test, range of motion test, and two-point discrimination test on the sole of the foot. Tests were conducted by physical therapists with five or more years of post-registration experience. Measurement of lower limb strength consisted of flexion and extension of the hip, knee, and ankle joints8). Measures of passive range of motion were obtained for the hip, knee, and ankle joints using a goniometer. A two point discrimination test9,10) was carried out using conditions and equipment as per Dellon et al 11). The points used for measurement were the plantar great toe and the heel, with each point investigated statically and dynamically. Each measurement was taken three times, and the values obtained from multiple correct answers were used.

In order to understand the level of fall risk in the elderly group, a clinical balance test (BBS) was carried out. Subjects in the elderly group were asked to perform 14 types of motor tasks, each of which was graded from 0 to 4, and an overall value was calculated. Taking the risk of falls into account, the tests were carried out on a one-to-one basis.

A posturograph (Kyowa Electronic Instruments Inc., JAPAN;ECG-1500B, sampling rate:100 Hz) was used to measure the trajectory of subjects' center of pressure (COP) in an upright stance in order to analyze their static balance ability. All subjects performed an eyes-open posturographic test for 60 s while staring at an object set 3 m ahead at eye level. At the time of the test, the lower limbs of the subjects were in the feet-together position and their arms were hanging naturally at their sides.

Subjects took the limit of stability (LOS) test to enable analysis of their dynamic balance ability. Subjects were asked to move, upon receiving a cue, left, right, forward and backwards, from an upright standing position to their maximum possible extended position without loss of balance. They were asked to try not to bend or stretch their waist, hip, or knee joints and only move their ankles. Large losses of balance, indicated by the arms moving away from the sides or if a subject took a step, were excluded from the analysis.

To determine COP of static posturographic measurements, speed (means and standard deviations of mediolateral, and anteroposterior sway), total trajectory length, and root mean square (RMS) area were calculated. For the dynamic stabilograph measurements (LOS test), the maximum COP displacements from the vertical position to the front, back, left and right were measured. The total of each of the maximum COP displacements in all four directions was also calculated12,13).

In order to investigate the effect of the gender of subjects in the elderly group upon their experience of falls, the group was split by gender. Each subgroup was further split into those who had experience of falls and those who had none, and the number in each group was compared. In order to investigate the effect of the angular limit of ankle dorsiflexion, subjects were split into a limited ankle dorsiflexion group and a normal group. Similarly, the proportion of subjects with limited ankle dorsiflexion was compared with both the group with experience of falls and the group without. Furthermore, multivariate analysis was used to investigate the relationship between fall rate and COP parameter, BBS score, and body function data.

The independent t-test was performed on the static and dynamic posturographic measurements. The chi-squared test was performed on the proportion of males vs. females amongst subjects with experience of falls, and the proportion of subjects with limited ankle dorsiflexion amongst subjects with experience of falls. The effect of each parameter was calculated using a discriminant function with the presence or absence of fall experience as the dependent variable and with static and dynamic stabilography measurements, BBS scores, and basic physical data as the independent variables.

RESULTS

Basic data and physical data for elderly group are shown in Tables 1 and 2, respectively. In the sensory examination the results for the static test were 13.0 ± 4.2 and 14.4 ± 3.7 mm for the heel and plantar area of the greater toe, respectively, and 11.3 ± 4.1 and 12.8 ± 3.6 mm for the dynamic test. The result of the grip strength test was 25.9 ± 7.3 kg for the elderly group. In the elderly group, 79 subjects (100%) were right hand dominant, and 74 subjects (94%) were right leg dominant. In the muscle strength test, all subjects in the elderly group scored over 4. There were 24 subjects (subjects with normal movement: 55) with a range of ankle joint motion of less than 10 degrees to either one or both sides.

The average of the BBS for the elderly group was 52.9 ± 4.0.

The result of the questionnaire showed that 25 subjects had experience of falls in the prior year (and 54 had no experience in the prior year).

The results of the factor investigation for the elderly and young subject groups are shown in Table 3. In the static test, the elderly group had statistically longer total trajectory length, and the standard deviation (SD) of the speed of
backward and forward movement was large. In the dynamic test, the elderly group’s maximum deviation away from the center of balance was significantly smaller than that of the young group.

The number of women with experience of falls within the elderly group was significantly higher than the number of men (5 men who fell vs. 24 who did not, 20 women who fell vs. 30 women who did not, p<0.05). However, there was no significant difference found in the proportion of subjects with experience of falls who had limited ankle dorsiflexion (8 subjects with vs. 17 without experience of falls within those with limited dorsiflexion; 17 with vs. 38 without experience of falls within those without limited dorsiflexion).

A comparison of male (n=29) and female (n=50) posturography data, basic data and body function data is shown in Table 4. A significant difference in the COP speed parameter (means and standard deviations of mediolateral, and anteroposterior sway) as well as in total trajectory length was found. No significant differences were found in the posturography values between the group with limited ankle dorsiflexion (n=24) and the group with normal ankle dorsiflexion (n=55).

The following function was derived from discriminant analysis:

\[ Z \text{ (discriminant function)} = 0.002 \times \text{total value of LOS test} + 0.139 \times \text{Grip Strength} - 4.01 \quad (p<0.05) \]

**Table 1. Basic data of the elderly group**

| Age (years) | 73.2 | 4.2 |
| Height (cm) | 156.9 | 6.7 |
| Weight (kg) | 56.0 | 8.2 |
| Foot length (cm) | 21.8 | 1.5 |
| Foot width (cm) | 9.3 | 0.8 |

**Table 2. Body function data of the elderly group**

| Grip strength (kg) | 25.9 | 7.3 |
| Two-point discrimination (mm) |  |
| SATIC |  |
| Great toe | 13.0 | 4.2 |
| Heel | 14.4 | 3.7 |
| Dynamic |  |
| Great toe | 11.3 | 4.1 |
| Heel | 12.8 | 3.6 |

**Table 3. Comparison of COP data between the elderly and young adults**

<table>
<thead>
<tr>
<th>Static Test</th>
<th>Elderly Adults (N=79)</th>
<th>Young Adults (N=70)</th>
<th>Average</th>
<th>SD</th>
<th>Average</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area (mm²) RMS</td>
<td>129.2</td>
<td>67.0</td>
<td>111.8</td>
<td>70.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Path length (mm)</td>
<td>2732.1*</td>
<td>359.2</td>
<td>2433.6</td>
<td>636.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SD, M-L</td>
<td>55.0*</td>
<td>7.6</td>
<td>52.2</td>
<td>9.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SD, A-P</td>
<td>39.9*</td>
<td>5.3</td>
<td>37.3</td>
<td>6.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average</td>
<td>45.5*</td>
<td>6.0</td>
<td>42.9</td>
<td>7.4</td>
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<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Dynamic Test</th>
<th>Elderly Adults (N=79)</th>
<th>Young Adults (N=70)</th>
<th>Average</th>
<th>SD</th>
<th>Average</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>COP maximum displacement (mm) Anterior</td>
<td>49.7*</td>
<td>15.5</td>
<td>73.2</td>
<td>11.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Posterior</td>
<td>46.2</td>
<td>15.0</td>
<td>48.4</td>
<td>12.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Right</td>
<td>49.7*</td>
<td>16.0</td>
<td>58.4</td>
<td>13.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Left</td>
<td>50.5</td>
<td>15.2</td>
<td>56.8</td>
<td>23.3</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*: p<0.05.

**Table 4. Comparison of COP data between the elderly and young adults**

**DISCUSSION**

This study investigated relationships between fall risk and measurements of static and dynamic posturography, basic physical data, and clinical balance test results in an elderly group.

The present results suggest that total score on the LOS test may be useful as a parameter related to falls. The LOS can be described as the maximum distance a person can intentionally displace his/her center of gravity14, or lean his/her body in a given direction without losing balance, stepping or grasping. It is necessary for the center of mass (COM) to remain within the LOS to maintain upright standing. However, LOS decreases significantly with age15, meaning that it becomes difficult for elderly people to keep COM within the LOS. Additionally, the impact of disturbing the sensory subsystems near the limit of stability is generally greater than that observed with the Sensory Organization Test in a relatively quiet stance16. The ability of elderly people to deal with sensory disturbance is also reduced17, and it is considered difficult for them to maintain balance near the LOS. The present results suggest that grip strength is one of the risk factors associated with fall frequency. Decreased grip strength is thought to be attributable to a decrease in general body strength18, as a result of which balance ability is thought to decline. In agreement with the present results, previous studies have reported that decreased grip strength is a risk factor for falls19,20.
When we analyzed the results by gender, the frequency of falls was higher among women than men, and COP speed was also larger in women. In addition, the significantly long total trajectory length also indicated that the female group had a greater sway and lower stability when standing upright. Maki et al. reported a significantly greater average COP speed in an elderly group with experience of falls than one with no experience of falls, when standing upright. Thus, our findings confirm these previous results regarding the relationship between COP speed and fall risk.

Investigation of age-related differences showed that the elderly group had a higher speed and longer total trajectory length than the young group. This finding was consistent with a previous study that reported that elderly individuals have reduced stability when standing upright.

It is believed that it is important for fall prevention measures to incorporate both sensory and motor approaches in order to be effective. Further, as it has been reported that it is necessary to upgrade living conditions as well as provide multifactor intervention, we believe that integrated intervention is required, including patient education.

**REFERENCES**


