Evaluation of trunk stability in the sitting position using a new device

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ABSTRACT
The purpose of this study was to evaluate trunk stability in seated elderly and young individuals using a new device that inclines a seat while tracking the center of pressure (CoP). We evaluated the locus of CoP, locus length, locus length per second, enveloped area, root mean square area, and locus length per unit area (LNG/AREA). LNG/AREA, which reflects postural adjustments controlled by the spinal proprioceptive reflexes of the lower limbs, was not significantly different between young and elderly individuals. Our device measured trunk stability without influence from the lower extremities, which explains why LNG/AREA did not significantly differ between young and elderly individuals. These findings indicate that the new device can be used to quantify dynamic trunk stability.

Age-associated changes in balance ability are associated with falls (6). In elderly individuals, falls are the leading cause of fractures of the lower extremities and decreases in quality of life. Elderly individuals who sustain a hip fracture can become bedridden and can experience systemic complications that result in death. In Japan, more than 70% of hip fractures occur as a result of falls (1). Therefore, balance needs to be evaluated to identify elderly individuals at risk of falls.

Evaluation of the balance is often performed using stabilometry, which is the objective study of body sway during quiet standing. Body sway increases with age (11). However, measurement of body sway in the standing position poses a fall risk to elderly individuals. Elderly individuals who sustain a hip fracture can become bedridden and can experience systemic complications that result in death. In Japan, more than 70% of hip fractures occur as a result of falls (1). Therefore, balance needs to be evaluated to identify elderly individuals at risk of falls.

Body sway measured in the anterior-posterior direction (sagittal plane) in the sitting position is not associated with body sway in the anterior-posterior direction in the standing position. However, body sway in the medio-lateral (coronal plane) direction is similar in sitting and standing positions (7). Medio-lateral balance decreases with age (17). Furthermore, a sideways fall onto the hip is a known risk factor for hip fracture in elderly individuals (8), indicating that medio-lateral balance should be evaluated when identifying risk factors for falls in elderly individuals. We designed a device that inclines a seat to the right and left in the coronal plane while tracking the center of pressure (CoP). In this study, we used this device to safely measure dynamic trunk stability in seated elderly and young individuals.

SUBJECTS AND METHODS
A total of 36 healthy elderly volunteers (mean age 77 ± 5 years) and 36 healthy young volunteers (mean age 26 ± 8 years) participated in this study (Table 1). No participants displayed neurological, vestibular or visual disorders. They did not have a history of falls.
in the past one year. A full explanation of this study was given to the participants before they agreed to take part in this study and informed consent was obtained.

Trunk stability was measured in a seated position using a novel device that we recently manufactured in-house (Fig. 1). This device has a speed-control motor with an AC electromagnetic brake (BHM62MT-G2; Oriental Motor Co., Tokyo, Japan) for load-bearing surfaces with a slant and is equipped with three triaxial force sensors (USL06-H5; Tec Gihan Co., Kyoto, Japan) to measure the reaction force. These sensors are located in the configuration of an isosceles triangle under the load-bearing surface. The load-bearing surface slants to a maximum of 3° and tracks the location of the CoP.

The height of the load-bearing surface was adjusted so that the participants were not able to touch the floor with their feet. Participants sat on the load-bearing surface of the device, kept their arms crossed to avoid protective reactions of the upper extremity and kept their gaze fixed on a point 2 m ahead (Fig. 2). The load-bearing surface of the device then inclined 3° to the right and 3° to the left and measured CoP over a period of 30 seconds (0.6 Hz) without pause. We measured trunk stability three times for each participant, and data from third repetition were used for analysis to exclude accidental motility because of inexperience.

The locus of CoP, locus length (LNG), locus length per second (LNG/TIME), enveloped area (ENV-AREA), root mean square area (RMS-AREA), and locus length per unit area (LNG/AREA; Table 2) were calculated. These parameters are commonly used in platform stabilometry (13, 16).

These parameters were compared across young and elderly participants using the Mann-Whitney test. All data were analyzed using SPSS version 19.0.
for Windows (SPSS Inc, Chicago, IL, USA). Significance thresholds were set at 0.01.

RESULTS
Fig. 3 shows examples of the locus of the CoP, which was larger in elderly participants than in young participants.

LNG was significantly shorter in the young participants than in elderly participants (1040.2 mm versus 1413.8 mm, \( P < 0.0001 \)), LNG/TIME was significantly lower in young participants than in elderly participants (34.7 mm/s versus 47.1 mm/s, \( P < 0.0001 \)), and ENV-AREA and RMS-AREA were significantly smaller in young participants than in elderly participants (335.3 mm\(^2\) versus 460.6 mm\(^2\), \( P = 0.0002 \) and 222.1 mm\(^2\) versus 399.2 mm\(^2\), \( P = 0.0019 \) respectively; Fig. 4). There was no significant difference between young and elderly participants in LNG/AREA (3.7 mm/mm\(^2\) versus 2.8 mm/mm\(^2\), \( P = 0.0293 \); Fig. 4). Complications, such as falls from the device, did not occur during the examination.

DISCUSSION
Trunk stability plays an important role in maintaining spinal posture and preventing falls. Lumbar kyphosis affects postural stability and represents a risk factor for falls (12). Lumbar kyphosis, spinal inclination, mobility of the lumbar spine, and mobility of spinal inclination are significantly associated with falls in elderly individuals (14). Back extensor strength is significantly associated with lumbar lordosis, indicating the potential importance of strengthening the back extensor muscles for improving or maintaining lumbar lordosis (9). Trunk stability seems to contribute to fall risk. There are many clinical assessment tools of balance (10, 20), but few quantitative evaluation tools for trunk stability (4, 22).

Balance control has four underlying factors; standing balance, ability to withstand perturbations, leaning balance with a stationary base of support, and dynamic balance with movement of the base of support (18). Most falls are due to sudden disturbance such as slip and trip (5). Therefore, evaluation of dynamic balance and the ability to withstand perturbations is required to identify fall risk.

Our device measured dynamic trunk stability in response to a perturbation in the medio-lateral direction. LNG/AREA did not significantly differ between young and elderly participants. LNG/AREA reflects minute postural adjustments controlled by the spinal proprioceptive reflex of the lower extremities.

**Table 2** Definition of outcome variables

<table>
<thead>
<tr>
<th>Variable</th>
<th>Description</th>
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<tbody>
<tr>
<td>LNG (mm)</td>
<td>Total distance traveled by the CoP</td>
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<tr>
<td>LNG/TIME (mm/s)</td>
<td>Total distance traveled by the CoP divided by time indicating sway speed</td>
</tr>
<tr>
<td>ENV-AREA (mm(^2))</td>
<td>Total area enveloped by the track of the CoP indicating the spatial spread of the swaying</td>
</tr>
<tr>
<td>RMS-AREA (mm(^2))</td>
<td>Root mean square area is a circle with the radius calculated as the mean distance between the CoP and each point of the track</td>
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<tr>
<td>LNG/AREA (mm/mm(^2))</td>
<td>Locus length per unit area indicating fine control of standing posture by proprioceptive reflexes</td>
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</tbody>
</table>

LNG: locus length, LNG/TIME: locus length per second, ENV-AREA: enveloped area, RMS-AREA: root mean square area, LNG/AREA: locus length per unit area, CoP: center of pressure
Fig. 3 A typical example of the locus of the center of pressure for one young participant and elderly participant. The locus is larger in the elderly participant than in the young participant.

Fig. 4 Box-plot diagrams of each parameter in young and elderly participants. LNG, LNG/TIME, ENV-AREA, RMS-AREA were significantly worse in elderly participants than in young participant. LNG/AREA was similar in the two groups ($P > 0.01$). N.S: Not significant, LNG: locus length, LNG/TIME: locus length per second, ENV-AREA: enveloped area, RMS-AREA: root mean square area, LNG/AREA: locus length per unit area, CoP: center of pressure
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ities (19). Our device measured trunk stability without any influence of the lower extremities, and this explains why LNG/AREA was similar in young and elderly participants. However, LNG, LNG/TIME, REC-AREA, ENV-AREA, and RMS-AREA were significantly worse in the elderly participants than in young participants. These findings indicate that dynamic trunk stability and the ability to withstand perturbation can be safely and precisely examined in elderly individuals with the new device.

In the future, the association between spinal curvature and fall risk assessment should be evaluated with tests widely used in the clinical setting, such as the Functional Reach Test (3) and the Timed Up and Go Test (15). Furthermore, it will be necessary to determine the relation between trunk stability and walking ability in elderly individuals with a risk of falls.

REFERENCES

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