Basic study of the new static stabilometry in the sitting position

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Objectives: In general, static stabilometry is measured by capturing the displacement of the center of foot pressure in the standing position. However, it is difficult to stand for aged or dizzy patients, and they may be at risk of falling. Thus, we have performed a basic study on static stabilometry in the sitting position.

Methods: We investigated 20 healthy adult subjects. None of the subjects displayed dizziness or had an equilibrium disorder. Measurements of static stabilometry in the sitting position were done by using a stabilometer on a sturdy stool. We evaluated the locus length, the enveloped area, the maximum amplitude of mediolateral (side to side), and the maximum amplitude of the anteroposterior, oscillation power area ratio.

Results: The locus length was significantly lower in the sitting position than in the standing position (P < 0.001). Unlike the situation in the standing position, the enveloped area in the sitting position was significantly lower when the eyes were closed than when they were open (P < 0.001).

Conclusions: Our examination unveiled characteristic data showing that the enveloped area and the locus length decreased when the eyes were closed. We investigated the static stabilometry in patients with chief complaints of dizziness and body sway due to otolaryngological or neurological causes.

Key words: static stabilometry, sitting stability, body sway, equilibrium function test
Static stabilometry in the sitting position

Materials and Methods

Subjects
This study was approved in advance by the Kitasato University institutional review board for observation and epidemiological study. We explained carefully the procedure to the subjects, and written informed consent was obtained from all of them: 8 healthy adult males (21−50 years old: mean 36.9 standard deviation [SD] ± 11.78 years) and 12 healthy adult females (21−50 years old: mean 30.0 [SD] ± 11.73 years) participated in the study. None of the subjects displayed dizziness or had an equilibrium disorder.

Materials
The measuring body sway device was the Anima GP-5000 (Figure 1). The GP-5000 sets the sampling frequency at 20 Hz, the sampling cycle at 50 msec, and the measuring time to 60 seconds. The stool for the sitting position is constructed of steel, and the size is 70 cm (H) × 80 cm (L) × (L) cm (H) (Figure 2). The top of the stool is made of plywood, and the even surface of the stool is confirmed with a level. The force-plate of the GP-5000 was attached to the stool (Figure 3).

The subject’s posture
The subject, in the sitting position, kept the feet dangling without touching the floor in order to reduce somatosensory inputs from the leg muscles, which have a significant influence on posture adjustment (Figure 4). Before beginning the measurements, the sitting position was regulated via the stabilometer such that the buttocks of the subject were located in the center of the force-plate of the GP-5000. The subject sat straight, keeping the arms crossed and both knees set at a comfortable position on the force-plate. In the standing position the

Figure 1. The stabilometer GP-5000 (anima)
Figure 2. The stool for the sitting position
Figure 3. The method of attaching the force-plate
Figure 4. Posture of sitting position
subject kept the feet close together according to the instructions of the Japan Society for Equilibrium Research.

**Measurement methods**

Before beginning the measurements, the subject's height, weight, and the height in the sitting position were recorded. The measurements were taken in the order of the standing position first (with eyes open, eyes closed), then in the sitting position (with eyes open, eyes closed). To avoid a discrepancy in the results due to fatigue and habituation, each measurement was taken only once. After the subject had attained the posture for each measurement, we started sampling the static stabilometry when the rolling of the subject's body became stable.

**Measurements of static stabilometry in the standing position (eyes open, eyes closed)**

The subject was asked to gaze at a circle, 1 cm in diameter, positioned 2 m in front of the subject. The subject kept the feet close together in a standing position on the stabilometer with the eyes open, and we measured the static stabilometry for 60 seconds. The subject then rested for 60 seconds, after which we measured the subject's eyes-closed static stabilometry for 60 seconds.

**Measurements of static stabilometry in the sitting position (eyes open, eyes closed)**

After the measurements in the standing position were taken, the GP-5000 force-plate was moved to the stool used for the sitting position measurements. The stabilometer was established at 180° horizontally removed from the normal setting position to avoid interference from the seating surface and the GP-5000 force-plate as shown Figure 3. After the GP-5000 force-plate was established on the stool, the subject was asked to sit on the force-plate with the eyes open as shown Figure 4, and we measured the height in the sitting position from the top of the subject's head to the seat surface with a tape measure. Then, we measured the sitting static stabilometry for 60 seconds. The subject then rested for 60 seconds, after which we measured the subject's eyes-closed sitting static stabilometry for 60 seconds.

**Verification test of the learning effect in the sitting position**

We measured the static stabilometry with the eyes open after the measurements with the eyes closed were taken to examine whether or not the learning effect would influence the measurements. We randomly chose 3 males and 3 females from among the subjects who had already participated in the examination, and then these subjects were measured under additional conditions.

**Study items**

We evaluated the locus length (LNG), the enveloped area (ENV-AREA), the maximum amplitude of mediolateral (side to side) (XD) sway, the maximum amplitude of anteroposterior (YD) sway, the maximum amplitude ratio (YD/XD), and the oscillation power area ratio in each position. And Romberg ratios were determined from each measurement. P-values were calculated with the Student’s *t*-test, and P < 0.05 was considered to indicate statistical significance.

**Results**

**The subjects’ body measurements**

The subjects’ body measurements are shown in Table 1. The average height of the 20 male and female subjects (mean age, 32.8 years SD ± 11.95) was 164.2 cm; the sitting average height was 88.6 cm; and their average weight was 58.0 kg. The ratios of standing height/sitting height were 0.53 (males) and 0.54 (females).

**Measurements of static stabilometry in the sitting position (eyes open, eyes closed)**

We measured the static stabilometry in a male subject (21 years old, 181 cm tall, who weighed 75 kg) in each position (Figure 5). The ENV-AREA was 0.06 cm² in the sitting position. This result was approximately 1/40

<table>
<thead>
<tr>
<th>Table 1. The subjects’ body measurements</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Total 20</strong></td>
</tr>
<tr>
<td>---------------------------</td>
</tr>
<tr>
<td><strong>Range</strong></td>
</tr>
<tr>
<td>Age</td>
</tr>
<tr>
<td>Height (cm)</td>
</tr>
<tr>
<td>Weight (kg)</td>
</tr>
<tr>
<td>Sitting height (cm)</td>
</tr>
</tbody>
</table>
Static stabilometry in the sitting position

of the ENV-AREA of 2.29 cm² in the standing position. Measurements of the static stabilometry in the sitting position showed mostly body sway in the anteroposterior direction.

Comparison of measurements in each position with eyes open and eyes closed

The measurements of LNG in the standing position and sitting position with the eyes open or closed are shown in Figure 6. The LNG in the sitting position was significantly lower than that in the standing position (P < 0.001), and in the sitting position, the LNG showed a tendency to decrease with the eyes-closed. The measurements of the ENV-AREA in the standing position and sitting position are shown in Figure 7. The ENV-AREA in the sitting position was significantly lower than that in the standing position with the eyes open or closed (P < 0.001). In the sitting position, the ENV-AREA was significantly lower in the eyes-closed position than in the eyes-open position (P < 0.05).

Comparison of the means of the oscillation power area ratios (%) in each position with each eye condition

The measurements of the body sway frequency of each condition were classified into three areas: 0.02 – 0.2 Hz (area A), 0.2 – 2 Hz (area B), and 2 – 10 Hz (area C), which were expressed as oscillation power area ratios (%); and we measured each area in the mediolateral (side
to side) direction, the anteroposterior direction, and the combined R direction (Table 2). When we compared the standing position with the sitting position at all body sway frequencies, the oscillation power area ratios (%) in the eyes-closed position were significantly lower than those in the eyes-open position in the sitting position (P < 0.001) in the 0.02–0.2 Hz area (area A). And the oscillation power area ratios (%) of the anteroposterior direction and the R direction in the sitting position were significantly lower than those in the standing position (P < 0.001).

The average of maximum amplitude ratio (YD/XD)
The averages of the maximum amplitude ratios (YD/XD) are shown in Table 3. The maximum amplitude ratios (YD/XD) in the sitting position were significantly

Figure 6. Comparison of locus lengths (LNG) in the standing and sitting positions

Figure 7. Comparison of enveloped areas (ENV-AREA) in the standing and sitting positions
Table 2. Mean of the oscillation power area ratio (%) in each area

<table>
<thead>
<tr>
<th>Area</th>
<th>Hz</th>
<th>Posture</th>
<th>Eyes</th>
<th>R-L direction</th>
<th>Fwd-Back direction</th>
<th>R-direction</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>mean (%)</td>
<td>mean (%)</td>
<td>mean (%)</td>
</tr>
<tr>
<td>A</td>
<td>0.02−0.2 Hz</td>
<td>Standing</td>
<td>Opened</td>
<td>25.28</td>
<td>33.53</td>
<td>23.15</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Closed</td>
<td>20.74*</td>
<td>24.15*</td>
<td>18.59*</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Opened</td>
<td>20.10*</td>
<td>20.90*</td>
<td>14.58*</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Closed</td>
<td>15.13</td>
<td>18.11</td>
<td>11.21</td>
</tr>
<tr>
<td>B</td>
<td>0.2−2 Hz</td>
<td>Standing</td>
<td>Opened</td>
<td>61.26</td>
<td>51.87</td>
<td>60.52</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Closed</td>
<td>65.62</td>
<td>59.62</td>
<td>62.42</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Opened</td>
<td>46.36</td>
<td>47.85</td>
<td>48.15</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Closed</td>
<td>47.48</td>
<td>49.33</td>
<td>48.45</td>
</tr>
<tr>
<td>C</td>
<td>2 Hz−10 Hz</td>
<td>Standing</td>
<td>Opened</td>
<td>13.46</td>
<td>14.60</td>
<td>16.33</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Closed</td>
<td>13.64</td>
<td>16.23</td>
<td>18.99</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Opened</td>
<td>33.54</td>
<td>31.25</td>
<td>37.27</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Closed</td>
<td>37.40</td>
<td>32.56</td>
<td>40.34</td>
</tr>
</tbody>
</table>

*P < 0.001

Table 3. Mean of the maximum amplitude ratio

<table>
<thead>
<tr>
<th>Posture</th>
<th>Eyes</th>
<th>Mean of the maximum amplitude</th>
<th>Fwd-Back (cm)</th>
<th>R-L direction (cm)</th>
<th>Ratio (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standing</td>
<td>Opened</td>
<td>2.22</td>
<td>1.95</td>
<td>1.14</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Closed</td>
<td>2.49</td>
<td>2.32</td>
<td>1.07</td>
<td></td>
</tr>
<tr>
<td>Sitting</td>
<td>Opened</td>
<td>0.64</td>
<td>0.38</td>
<td>1.68**</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Closed</td>
<td>0.51</td>
<td>0.23</td>
<td>2.22**</td>
<td></td>
</tr>
</tbody>
</table>

**P < 0.001

Figure 8. Relations between height and LNG
Figure 9. Relations between height when sitting and LNG

Figure 10. Relations between weight and LNG

Table 4. Verification test of the learning effect in the sitting position

<table>
<thead>
<tr>
<th>Subject</th>
<th></th>
<th></th>
<th>Enveloped area (cm²) of sitting position</th>
<th></th>
<th>Locus length (cm) of sitting position</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Standard method*</td>
<td>Reverse method**</td>
<td>Standard method*</td>
<td>Reverse method**</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Eyes opened</td>
<td>Eyes closed</td>
<td>Eyes opened</td>
<td>Eyes closed</td>
<td>Eyes opened</td>
</tr>
<tr>
<td>A</td>
<td>0.091</td>
<td>0.028</td>
<td>0.027</td>
<td>0.021</td>
<td>17.494</td>
</tr>
<tr>
<td>B</td>
<td>0.069</td>
<td>0.031</td>
<td>0.080</td>
<td>0.069</td>
<td>23.759</td>
</tr>
<tr>
<td>C</td>
<td>0.072</td>
<td>0.029</td>
<td>0.064</td>
<td>0.053</td>
<td>20.383</td>
</tr>
<tr>
<td>D</td>
<td>0.036</td>
<td>0.028</td>
<td>0.060</td>
<td>0.029</td>
<td>19.519</td>
</tr>
<tr>
<td>E</td>
<td>0.044</td>
<td>0.036</td>
<td>0.072</td>
<td>0.043</td>
<td>22.917</td>
</tr>
<tr>
<td>F</td>
<td>0.124</td>
<td>0.055</td>
<td>0.299</td>
<td>0.096</td>
<td>25.449</td>
</tr>
<tr>
<td>Average</td>
<td>0.073</td>
<td>0.035</td>
<td>0.100</td>
<td>0.052</td>
<td>21.587</td>
</tr>
</tbody>
</table>

*Standard method: from eyes open to eyes closed
**Reverse method: from eyes closed to eyes opened
higher compared with those in the standing position (P < 0.001).

**Relationship between LNG and the subjects’ body measurements**

We show the relationship between the subjects' LNG and height according to gender (Figure 8). There were no significant differences between males and females. We also show the relationship between LNG and height of subjects in the sitting position according to gender (Figure 9). Again, there were no significant differences between males and females. In the relationship between LNG and body weight, the LNG of females showed a tendency to increase with increased body weight (Figure 10).

**Verification test of the learning effect in the sitting position**

We show the relationship between the standard methods (from eyes open to eyes closed) and then the reverse (from eyes closed to eyes open) (Table 4). There were no changes in the tendency to show restraint in the LNG and ENV-AREA.

**Discussion**

Clinical studies of stabilometry in the sitting position have been reported in the field of physiotherapy for rehabilitation.6-10 But there are few basic reports published in the field of clinical examination for dizziness or body sway and the focus of healthy subjects. Amemori et al.11 reported a basic study of body sway in the sitting position under an alcohol-induced condition. In their report, these authors suggested that the clinical examination of body sway in the sitting position is as feasible as doing it in the standing position. And Uchiyama et al.12 examined the body sway in the sitting position in a study that was designed to have clinical application in the field of physiotherapy. They also suggested that the sitting position is as feasible to use as is the standing position. But interpreting the clinical significance of a basic study of body sway is difficult because examination methods have not yet been standardized, e.g., the posture in the sitting position, the measurement device, the measurement methods, among others. In the field of physiotherapy, body sway is measured including dynamic stabilometry, which is accompanied by exercising the trunk and arms. In clinical examinations, the body sway is measured by static stabilometry for the purpose of determining the trunk stability, unlike physiotherapy, which includes dynamic stabilometry. Therefore, there is a difference between the clinical examination and physiotherapy. Generally, most of the examinations medical technologists perform are done on dizzy and aged patients. Considering these circumstances, to avoid the risk of falls in the standing position, a safe examination avoids the standing stabilometry.13-15 If clinical examinations of the body sway are enabled in the sitting position, the usefulness of examinations increase because of reducing the possibility of falling. However, currently the sitting stabilometry is not commonly used in clinical examinations.

**Setting method of the stool and the force-plate**

In the present study, for the examination of static stabilometry in the sitting position, the GP-5000 force-plate was positioned on the top of the stool, and the subjects sat directly on the force-plate. In this method, because the position of the center of gravity of the body became lower than that of the standing position, all the parameters of the body sway, such as the LNG, were significantly lower than those in the standing position. In some studies, the stool was positioned directly on the force-plate, and the subject sat on the stool. In this method, because the distance from the force-plate to the seat surface was set to be longer in comparison with that in the standing position, in one report the apparent measured values increased compared with those obtained when the subject sat directly on the force plate positioned on the stool.12

**Sitting position of the subjects and sway forms**

In the present study, because we conducted the sitting stabilometry with the subjects sitting directly on the stool, these measurements are actual values that are not modified by the difference in the height or the type of the stool. If the stool is set directly on the force-plate, it is possible to predict that the measurements have many variables due to the size and shape of the stool. And in an actual clinical examination, it has been reported that the body sway increases remarkably when the feet are dangling without touching the floor. Therefore, it is thought that the feet should not touch the floor. Because of the difference in the height and length of the lower limbs of patients, and if the feet are dangling without touching the floor, it is difficult to perform the examination under standardized conditions, because it then becomes necessary to adjust the height of the stool for each individual. Therefore, the subject is required to sit directly on the force-plate for the examination.

As a characteristic of sitting stabilometry, we found that the body sways in the sitting position were in the anteroposterior direction in all of the subjects. It has
been reported that the standing stabilometry of healthy persons shows various movements, such as anteroposterior, diffuse, afferent, and multicenter types.\textsuperscript{16,17} Noro et al.\textsuperscript{18} reported that the peak seat surface pressure in the sitting position could be distinguished as three parts: the gluteus maximus, ischial tuberosity, and femoral regions. On the force-plate, the main contact surfaces are the gluteus maximus and the right and left femoral regions. Therefore, the stability for the body sway in the mediolateral (side to side) directions is increased, and the body sway in the anteroposterior direction became the main component, which was not a variety of sway forms in healthy subjects.

\textbf{Results of the Romberg ratios}

In general, because the visual input represents the source of information that is important to posture adjustment in standing stabilometry, the body sway increases when the eyes are closed compared with that when the eyes are open. Therefore, the Romberg ratios of measurements are often determined as more than 1.00. However, in the present study, the Romberg ratios of the LNG and the ENV-AREA were determined to be less than 1.00. Because the contact areas of the subject increase in the sitting position compared with those in the standing position, the learning and revision effects from somatosensory inputs may more greatly influence the measurements taken in the sitting position by being taken twice. To confirm the influence of the learning and revision effects of the cerebellum, we performed the eyes-closed examination before the eyes-open examination. In this way, if there were any influences on the measurements, they were considered to be insignificant.

In a basic study of body sway in the sitting position by Amemori et al.,\textsuperscript{11} a similar result has been recognized in LNG measurements. However, in their study, the reason for this phenomenon was not discussed. In the standing position, it has been reported that the Romberg ratio becomes less than 1.00. Ohashi\textsuperscript{19} stated that the Romberg ratios may become less than 1.00 in a patient with a cerebellum disorder. And Okuzono\textsuperscript{20} found that the body sway in the standing position may decrease with the eyes closed in healthy subjects, and in many elderly subjects the phenomenon tends to be the reverse of that seen in young subjects. In the present study, because the Romberg ratio was less than 1.00 even in young healthy subjects in the sitting position, it was thought that the regulatory mechanism of the equilibrium function was different from that in the standing position. In the sitting position with the eyes closed, the information from visual and somatosensory inputs decreases remarkably; consequently, the quantity of information processing for posture stabilization with the cerebellum is reduced compared with that in the standing position. As a result, it is thought that the processing capacity of the cerebellum improved, and a more stable posture in the sitting position was attained. A future theme of our continued investigation will be the study of the Romberg ratio as it relates to the various disabilities in the sitting position.

Regarding characteristics of sitting stabilometry, with the exception of the lowering of the Romberg ratios with the eyes closed, we found that the body sway movement in the anteroposterior direction was greater than that in the mediolateral (side to side) direction. And we found that the oscillation power area ratio (%) of the anteroposterior direction in the relatively low frequency of 0.02−0.2 Hz showed a tendency to decrease in the sitting position compared with the standing position in all measurements. Especially, in the mediolateral direction, it was significantly decreased with the eyes closed. It was thought that the body sway at low frequency was decreased because the distance from the force-plate to the center of gravity in the sitting position was lower than that in the standing position. With regard to the significant decrease in the oscillation power area ratio (%) of the mediolateral direction in the eyes-closed position, it may be a factor that the Romberg ratios decreased at the eyes-closed position, but the reason for that is also not clear.

\textbf{Relations with the physical measurements and results of the sitting position}

The static stabilometry in the standing position is said to be influenced by factors such as height, weight, age, and gender.\textsuperscript{16} On the other hand, among other examinations, a report showed that there was only a significant association between age change and static stabilometry.\textsuperscript{21} In that study,\textsuperscript{21} there was no association between height, height when sitting, gender, and the LNG. In static stabilometry in the sitting position with the lower limbs off the ground, the body maintains balance with the upper part of the trunk and the lower limbs, which are mainly supported by the seat surface. Therefore, we examined the potential relationship between body sway and the length of the lower limbs, which reduced the height in the sitting position from that in the standing position; however, there was no significant relationship between them. Because the length of the lower limbs is about half of the height in the sitting position, especially, when both legs are off the ground, the height is defined only by the length of the leg below the knee, which a subject can move freely. Therefore, it is thought that the length of
the lower limb rarely affects the body sway. Because there were too few subjects of different ages, a potential age effect was not evaluated in the present study.

Conclusion

We performed a basic study on static stabilometry in the sitting position in healthy adult subjects. Our examination revealed characteristic data showing that the LNG and the ENV-AREA decreased when the subjects' eyes were closed. Accumulating more data on healthy subjects in the future is warranted. Furthermore, in our own future studies, based on these examination results, we will investigate the static stabilometry in patients with the chief complaints of dizziness and body sway due to otolaryngological and neurological causes.

References