Measurement of asymmetric sitting posture using unstable board with accelerometer

Ji-Yong Jung, In-Sik Park, Bong-Ok Kim, Tae-Kyu Kwon, Yonggwan Won and Jung-Ja Kim

***Abstract*—**Postural balance has a significant effect on activities in daily life continuously. The objective of this study was to evaluate the effect of pelvic asymmetry on postural balance during sitting. For accurate analysis, we developed sitting posture measurement system using unstable board with accelerometer. 5 pelvis asymmetry patients and 5 control subjects were participated in this study. Subjects were instructed to perform static and dynamic sitting. Angle variation in the frontal and sagittal plane as well as body pressure distribution of left and right side including maximum force, peak pressure, mean pressure, and area were assessed while sitting. Also, intra class correlation coefficient was used to evaluate the reliability of the system. In comparison with mean angular variation and pressure distribution between two groups, all parameters were more tilted to left side than right side in pelvic asymmetry group. And, the reliability of the measurement system was excellent in both static and dynamic sitting. From these results, we observed negative effect of pelvic asymmetry on postural balance and it can cause asymmetric sitting posture. This paper suggested that measuring method using unstable board with accelerometer may be suitable for evaluation of postural asymmetry, and this system can be utilized to provide useful information about patients with pelvic asymmetry in clinical medicine.

***Keywords*—**Postural balance, Pelvic asymmetry, Sitting posture, Unstable board, Accelerometer

I. Introduction

Prevalence of patients with pelvic asymmetry induced by leg length discrepancy (LLD), is defined as a condition in which a disparity of length between the legs, increased by approximately 40~70% in the general population [1]. Pelvic asymmetry is relatively common, and most people actually have mild asymmetry with no noticeable symptoms. Previous studies reported that postural imbalance caused by leg length discrepancy and pelvic asymmetry has been associated with altered trunk motion, increased strain on body segment, low back pain, scoliosis, and gait abnormality. And it can negatively influence on the individual's activities in daily life continuously [2-10].

With the change of social structure and working condition, prolonged sitting has become the most common posture at work. Maintaining correct posture is essential to prevents injuries, reduces the stress on the ligaments, allows muscles to work more efficiently, and provides normal biomechanical functions of the body and musculoskeletal system [11]. However, prolonged sitting during working can influence on forming bad sitting posture like leaning back on a chair and sitting cross-legged. These postural changes are connected to continuous functional damage to balance control system [12]. Also, bad sitting posture over a long period of time can lead to long term complications such as osteoarthritis [13]. Although there is evidence that how pelvic asymmetry affect the postural stability in static standing [14-15], sitting [7,16], and during walking [17-18], the differences of postural balance in unstable sitting posture between symptomatic and asymptomatic person has not been studied.

In recent years, many studies related to the measurement of physical activity using accelerometer have been conducted [19-20]. Accelerometers are commonly utilized to detect the motion in various clinical fields as its advantage of cost, size, and portability. Bliley et al. [21] developed compact motion analysis system using MEMS accelerometer to collect information about body posture and movement. Luo et al. [22] demonstrated that posture monitoring system based on an accelerometer for training people can used to assess postural changes and positively influence on improved postures. Curone et al. [23] detected human activity and posture using new algorithm based on real-time three-axis accelerometer data placed on the trunk, and confirmed the accuracy of this real-time analysis classifier was good. Sprager and Zazula [24] proposed a method for identifying walking pattern and gait cycle from accelerometer data. Thus, clinical quantitative measurement system using accelerometer which is a promising technique can be used to provide postural information while sitting for individual and to prevent progression in patients with pelvic asymmetry.

In this study, we assessed the differences of postural balance between the patients with pelvic asymmetry and healthy subjects in unstable board with accelerometer to observe the

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effects of pelvic asymmetry on posture balance during sitting.

II. Experimental Method

A. Subjects

5 pelvic asymmetry patients (PA) group and 5 pelvic symmetry subjects (PS) group were included in this study. The mean age, height, body weight of two groups was 14.41±1.34 years, 16.58±10.54 mm, and 61.43±12.48 kg, respectively. In PA group, patients which were diagnosed pelvic asymmetry with LLD were recruited from an outpatient foot clinic. A posteroanterior full spine standing X-ray was performed to evaluate the differences between the left side and the right side in the iliac crest. Height of the right pelvis was higher than left pelvis, and the difference of length between the legs was 6.99±2.91 mm as shown in Fig. 1. Exclusion criteria of PA group were pain of the lower extremity, pelvic or LLD correction, or other postural training. Inclusion criteria for PS group were no previous spinal disorders or history of injury in the musculoskeletal system, or disease related to asymmetry of the lower extremity. All participants were informed a full explanation regarding the protocol and provided written consent prior to their participation.

B. Measurement Instrument

Shape and appearance of unstable board with accelerometer which was developed to assess the postural balance of subjects was hemisphere. The dimensions of the unstable board were as follows: length 370 mm, width 320 mm, height 85 mm. The curvature radius of this board was 320 mm. It can create maximum around 20 degrees in the sagittal and frontal planes. Seat surface of this board was covered with soft material to provide comfort during sitting as shown in Fig. 2.

Accelerometer (MMA7331L, Freescale Semiconductor Inc., Austin, Texas) which was positioned to middle bottom of the board measure acceleration in a range of ±4 g and sensitivity was about 86.3 mV/g. This position of sensor facilitated measurement on neutral and asymmetry sitting posture. Also, photo sensors (SG-23FF, Kodenshi Co., Tokyo, Japan) were attached to the surface of both sides in board to check sitting state of subjects by measuring the gap between the inner tip and plate. These sensors employed to use the energy more efficiently by operating the measurement system during sitting.

Fig. 1 Standing anteroposterior(A-P) radiograph

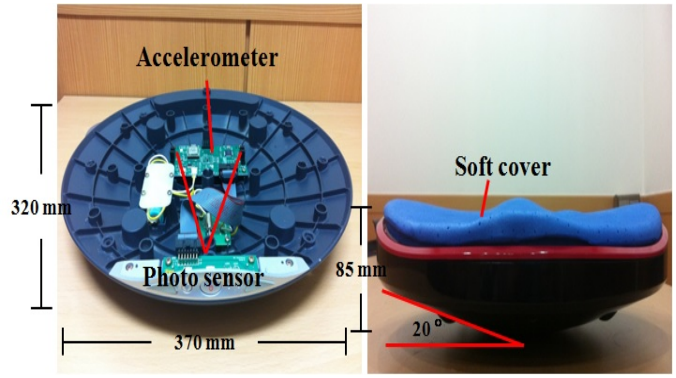


Fig. 2 Sitting posture measure system

Accelerometer output included the acceleration of gravity, vibration, and acceleration transformation. Therefore, a third-order digital finite impulse response (FIR) low-pass filter at 2 Hz was used to correct the sensor output. Tilting angle was calculated using acceleration of gravity and the formula that was used to calculate angle value by using accelerometer was as follows Eq. (1):

$$\theta = \tan^{-1}\left(\frac{y}{z}\right) \qquad (1)$$

C. Experimental Protocol

To measure the asymmetry of sitting posture, measurement system was located in the center of stool. The experimental procedure was divided into two conditions as follows: static and dynamic sitting. In static condition, subjects were instructed to sit in their usual manner on the unstable board with their arms crossed on contra-lateral shoulders for 30 seconds as shown in Fig. 3. In dynamic sitting condition, subjects were asked to perform anterior, posterior, left, and right pelvic rotation with trying to fix their upper trunk, and then they keep this sitting posture for 5 seconds, respectively, as shown in Fig. 4. A foot support was used to prevent the influence of leg movement, and it was adjusted to support the feet by keeping knee and ankle angles at 90° [25-27]. Before the experiment, all subjects practiced all testing procedure until they could understand about all postures. To prevent fatigue, subjects took a 5 minute rest in between experiments.

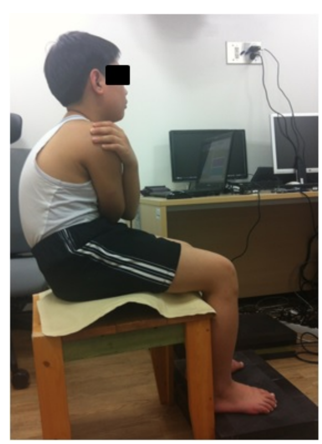


Fig. 3 Static sitting posture

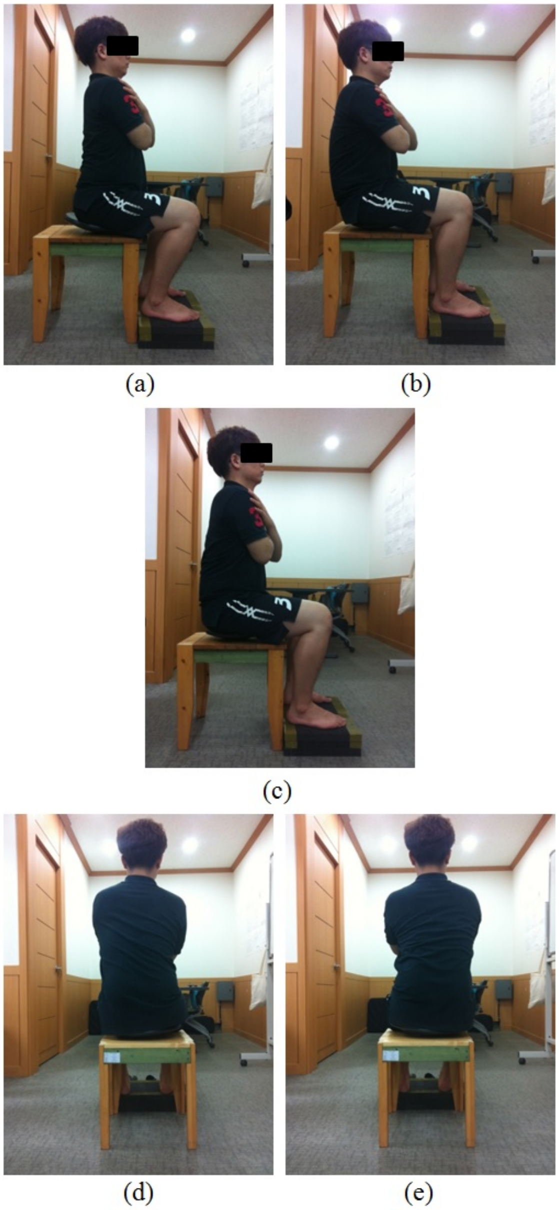


Fig. 4 Dynamic sitting posture
(a) Anterior pelvic rotation, (b) Posterior pelvic rotation,
(c) Neutral pelvic position, (d) Left pelvic rotation,
(d) Right pelvic rotation

D. Data Analysis

Angle variation data (sampling rate: 100 samples/s) in the frontal and sagittal plane collected by sitting measurement system were analyzed using LabVIEW 2010 (National Instrument Co., Texas, USA). X-axis was presented to right (+) and left (-) direction in frontal plane, and Y-axis was presented to anterior (+) and posterior (-) direction in sagittal plane. The COP (center of pressure) of the subject was computed using accelerometer data. Pressure distribution was analyzed to contact area, maximum force, peak pressure, and mean pressure. These data were divided into 2 regions of masks (left and right) and defined using Novel Software (Novel Gmbh, Munich, Germany). For accurate analysis, pressure data were normalized by body weight of subjects.

Postural stability was evaluated using COP data from accelerometer and pressure distribution during static and dynamic sitting. To perform this evaluation, the average distance of the COP sway and total COP sway area was analyzed [28-29]. COP sway path and area was calculated as follow Eq. (2) ~ (7):

$$COPpath = \sum_{n=1}^{N-1} \sqrt{(COP_{n+1}^{AP} - COP_{n}^{AP}) + (COP_{n+1}^{ML} - COP_{n}^{ML})^2} \quad (2)$$

$$a_n = \sqrt{(COP_n^{AP})^2 + (COP_n^{ML})^2} \quad (3)$$

$$b_n = \sqrt{(COP_{n+1}^{AP} - COP_n^{AP})^2 + (COP_{n+1}^{ML} - COP_n^{ML})^2} \quad (4)$$

$$c_n = \sqrt{(COP_{n+1}^{AP})^2 + (COP_{n+1}^{ML})^2} \quad (5)$$

$$S_n = \frac{a_n + b_n + c_n}{2} \quad (6)$$

$$COParea = \sum_{n=1}^{n-1} \sqrt{S_n \cdot (S_n - a_n) \cdot (S_n - b_n) \cdot (S_n - c_n)} \quad (7)$$

where N was the total number of samples, n was the sample number, a_n was the length from center (0,0) to n, b_n was the length from n to $n+1$, c_n was the length from center (0,0) to $n+1$, and s_n was total sum of a_n, b_n, and c_n divided by 2. Data from all 3 trials were analyzed.

Statistical analysis was performed using SPSS 18.0 software (SPSS Inc., Chicago, USA). Independent t-test was used to examine the difference in angle variation and pressure distribution between PA and PS group, at $p < .05$ level. Also, intra-class correlation coefficient (ICC) was analyzed to evaluate the reliability of the system.

III. Results

A. Mean Angular Variation

Mean angular variation in anterior-posterior (AP) and left-right (LR) direction during static and dynamic sitting is shown in Fig. 5~8, respectively.

In static sitting, mean angle of both groups were tilted to posterior and left direction. Tilting angle value of PA group was smaller than PS group in AP direction. In contrast, tilting angle of PA group was significantly larger than PS group in LR direction (p=0.013).

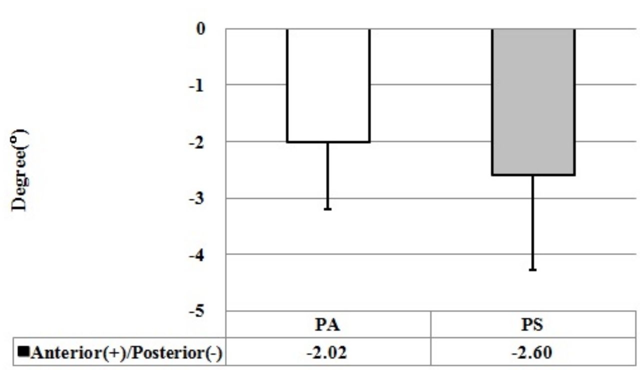
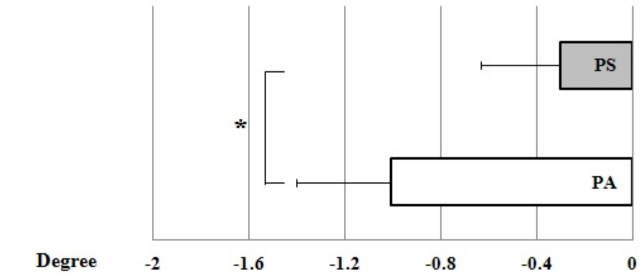
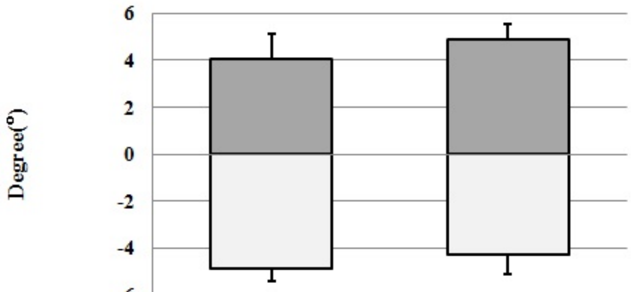


Fig. 5 Anterior and posterior tilt angle in static sitting



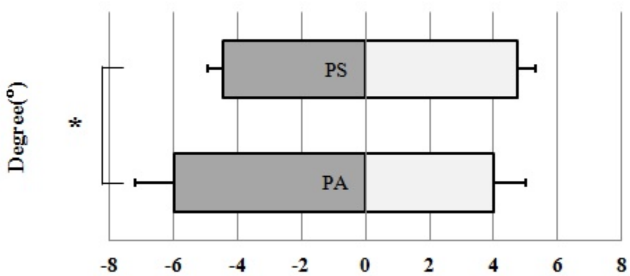
	PA	PS
■Left(-)/Right(+)	-1.01	-0.30

Fig. 6 Left and right tilt angle in static sitting (*p < .05)



	PA	PS
■Anterior Tilt	4.06	4.87
□Posterior Tilt	-4.90	-4.27

Fig. 7 Anterior and posterior tilt angle in dynamic sitting



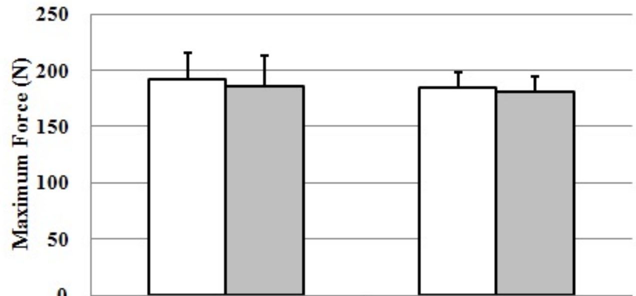
	PA	PS
■Left Tilt	-5.97	-4.44
□Right Tilt	4.00	4.74

Fig. 8 Left and right tilt angle in dynamic sitting (*p < .05)

In dynamic sitting, there was a difference in angular variation between PA and PS group during anterior and posterior pelvis rotation as shown in Fig. 7. Posterior pelvic tilt angle of PA group and anterior pelvic tilt angle of PS group was larger than pelvic tilt angle in angle between PA and PS group. Difference in angular variation during left and right pelvic rotation is presented in Fig. 8. The major difference in the angle was evident in the left and right pelvic tilt of PA group. In PA group, value of angle was significantly more tilted to left side than right side while there is a little difference in tilting angle between left and right side in PS group.

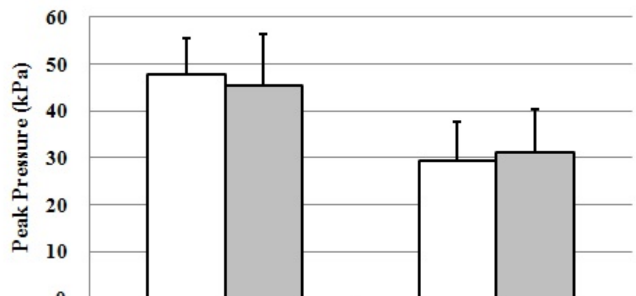
B. Pressure distribution

The contact area, maximum force, peak pressure, and mean pressure of left and right side are presented in Fig. 9~12. In PA group, maximum force, peak pressure, and mean pressure



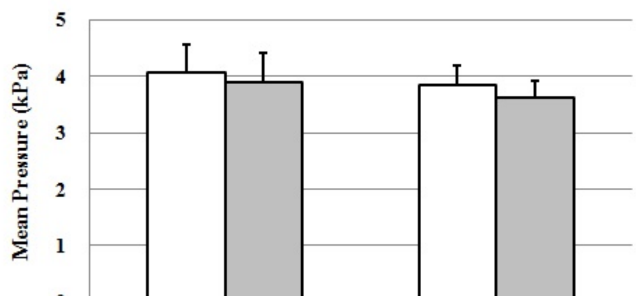
	PA	PS
□Left	191.96	184.82
■Right	185.96	181.05

Fig. 9 Maximum force



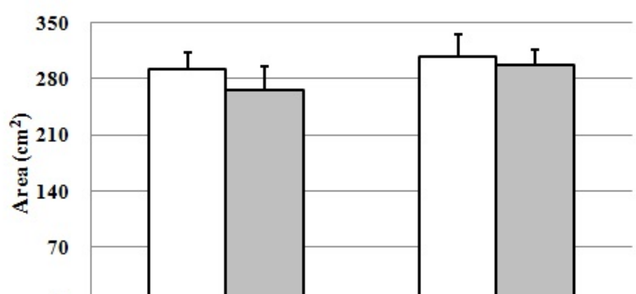
	PA	PS
□Left	47.85	29.33
■Right	45.43	31.25

Fig. 10 Peak pressure



	PA	PS
□Left	4.06	3.83
■Right	3.89	3.61

Fig. 11 Mean pressure



	PA	PS
□Left	292.52	307.73
■Right	266.25	296.92

Fig. 12 Area

of left side was higher than right side while area of left side was lower than right side. In PS group, maximum force, mean pressure, and area of left side was higher than right side while peak pressure of left side was lower than right side. In comparison with both sides of contact area, maximum force, peak pressure, and mean pressure between PA and PS group, all pressure parameters except for area data of PA group during sitting was higher than PS group.

C. Postural stability

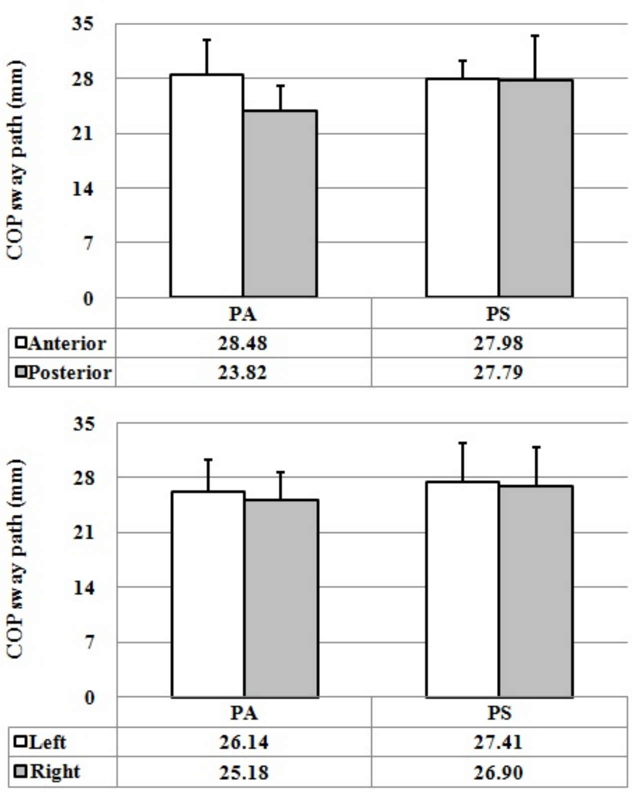
COP sway path and area between PA and PS group during sitting is presented in Fig. 13~14. As shown in Fig. 13, there was a big difference in center of pressure distance while performing anterior and posterior pelvic rotation in PA group. Also, difference in sway area between left and right pelvic rotation tilt was larger in PA group than PS group as shown in Fig. 14.

D. Repeatability of the system

Average distance of COP sway path and area did not differ significantly in the first test as compared with the second test as shown in Fig. 15. By observing the ICC of COP sway path and area between first and second test for static and dynamic sitting posture, we could confirm the reliability of the system. The ICC value for COP sway path ranged from 0.86 to 0.96 and COP area ranged from sitting posture measurement system ranged from 0.81 to 0.95

IV. Discussion

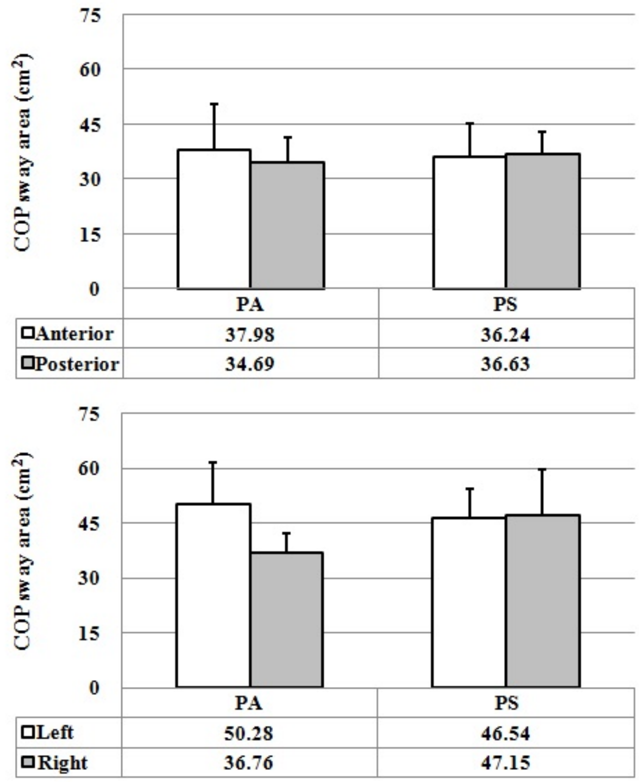
We compared static and dynamic sitting posture between PA and PS group using measurement system with accelerometer.



	PA	PS
Anterior	28.48	27.98
Posterior	23.82	27.79

	PA	PS
Left	26.14	27.41
Right	25.18	26.90

Fig. 13 COP sway path between PA and PS group



	PA	PS
Anterior	37.98	36.24
Posterior	34.69	36.63

	PA	PS
Left	50.28	46.54
Right	36.76	47.15

Fig. 14 COP sway area between PA and PS group

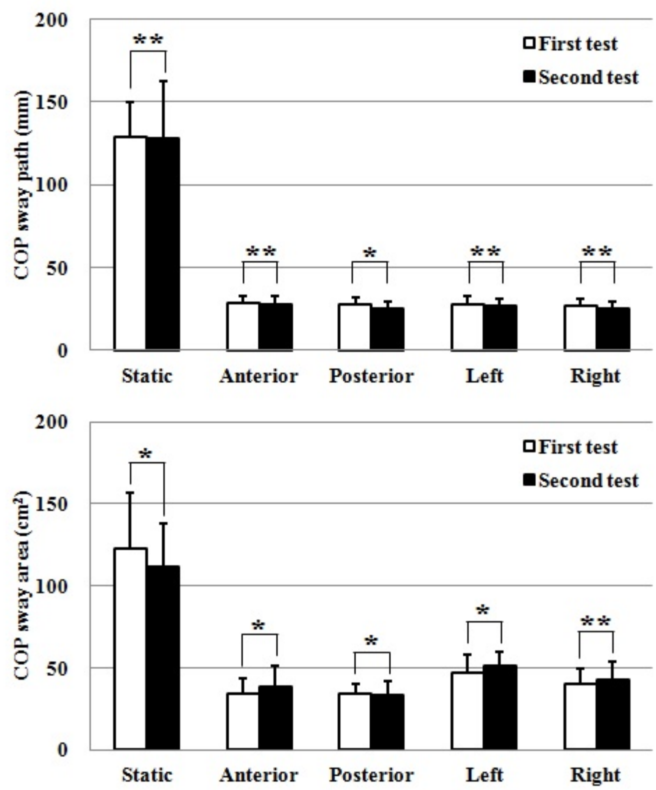


Fig. 15 COP sway area between PA and PS group (**p < .01, *p < .05)

Height of right pelvis was high compare with left pelvis in PA group. In static sitting, PA group showed an asymmetry which is more tilted 1.01° to left side than right side, and there is a significant difference between both groups. Postural asymmetry during static sitting may affect to perform anterior, posterior, left, and right side pelvic rotation. Significant angular difference in LR direction was 1.97° with left tilt in PA group during dynamic sitting. In pressure distribution, maximum force, peak pressure, and mean pressure of left side was higher than right side. Also, all pressure parameters except for area data of PA group during sitting was higher than PS group. Differences in these tilting angle and pressure distribution are associated with the COP sway path and area. There was a difference in distance and sway area of center of pressure during dynamic sitting. As compare with COP results on left and right side of PA group, COP sway path and area of left side more increased than right side compare to that of PS group. Generally, in case of difference in length exist between the legs, length asymmetry is not reduced while it can cause pelvis deformation in frontal and sagittal plane, and negatively influence on standing posture as well as sitting posture by compensation [30-31]. From these results, PA group have asymmetrical balance as well as damaged balance system induced by pelvic asymmetry during static and dynamic sitting.

It has been suggested that ICC values in a range of 0.75 to 1.00 was considered as excellent; 0.60 to 0.74 as good; 0.40 to 0.59 as fair; less than 0.40 as poor [32]. Our results showed excellent reliability in both static and dynamic sitting. Test-retest reliability of the measurement system demonstrated high ICC values ranged from 0.81 to 0.96. It means that this sitting posture measurement system may be useful for measuring the postural asymmetry.

V. Conclusion

In this study, we evaluated the differences of postural balance between the patients with pelvic asymmetry and healthy subjects using unstable board with accelerometer. The value of angle variation was tilted with the degree of asymmetry of the pelvis in both static and dynamic sitting condition. And maximum force, peak pressure, and mean pressure was distributed asymmetrically. Accordingly, postural imbalance caused by asymmetry of pelvis was associated with asymmetric sitting posture. Also, the reliability results for the measurement system were excellent in static and dynamic sitting. From these results, we observed negative effect of pelvic asymmetry on postural balance and it can cause asymmetric posture. This paper suggested that unstable board with accelerometer may be suitable for evaluation of postural asymmetry, and it can be utilized to proved useful information about patients with pelvic asymmetry in clinical medicine as well as sitting postural change of patients with disease such as LBP, scoliosis, and disc. Further research is required to compare the trunk muscle activation pattern and kinematics between patients with pelvic asymmetry and normal subjects.

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