

# The radiographic assessments of spino-pelvic compensation using IoT-based real-time ischial pressure adjustment: clinical research study

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## Research Article

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# Abstract

**Background:** In malalignment syndrome, the spino-pelvic alignment correction with foot orthotics can be applied only to a standing position in the coronal plane. Considering the fact that the average time Koreans spend sitting in a chair is 7.5 hours per day, studies on spino-pelvic correction in sitting position is needed. The purpose of this study is to investigate the pressure changes and radiographic assessment of spino-pelvic alignment using a chair equipped with a height-adjustable seat-plate.

**Methods:** Experiments were conducted on 30 research participants. The inclusion criteria for the participants were as follows: The volunteers of nonstructural malignment syndrome with shoulder height differences (SHDs) or iliac flea height differences (ICHDs) greater than 5 mm in radiographic images excluding participants with structural deformity. All participants were subjected to measure buttocks interface pressure while seated using a smart chair in three consecutive steps: (1) on initial seated, (2) on balancing seated, and then (3) on 1hr balancing seated. Radiographically, the five spino-pelvic parameters such as SHD, ICHD, LLD, POA, and coronal imbalance were analyzed to investigate the effect of pelvic imbalance compensation on spino-pelvic alignment.

**Results:** Pelvic imbalance was compensated with seat plate height adjustment in average of  $3.6 \pm 1.8$  mm, so that the pressure discrepancy improvement between buttocks from  $36.4 \pm 32.3$  on initial seated to  $15.7 \pm 20.3$  on balancing,  $12.7 \pm 10.9$  on 1hr balancing seated ( $\Omega$ ,  $p=0.008$ ). The radiographic changes before and after pelvic imbalance compensation demonstrated a statistically significant improvements of spino-pelvic parameters on sitting and standing: at the average value of -0.9 to -0.8 and 9.5 to 2.5, SHD and ICHD, respectively (mm,  $p=0.005$ , 0.037) and -3.0 to -1.0, 1.8 to 0.8, and 0.8 to 0.1, SHD, ICHD, and LLD, respectively (mm,  $p=0.005$ , 0.016, 0.033).

**Conclusions:** Spino-pelvic malalignment can be improved by individually customized pelvic compensation using balanced seat plate height adjustments under the real-time pressure sensing and monitoring on the buttocks while seated.

## Introduction

Malalignment syndrome was defined by Wolf Schamberger, as follows: malalignment associated biomechanical changes, especially a shift in weight bearing and asymmetries of muscle tension and strength, and joint ranges of motion affecting soft tissues, joints, and organ systems throughout the body(1). The pelvis transfers loads generated by body weight and gravity during standing, walking and sitting and acts as a basis for the axial system(2, 3). According to Schamberger et al there are three common presentations of pelvic malalignment; rotational malalignment, upslip of the sacroiliac joint, and inflare/outflare. Pelvic alignment influences spinal posture and stability, and pelvic malalignment is a common cause of lower back, hip, and leg pain. The symptoms and signs of malalignment syndrome include persistent foot, leg, or low back pain, change of the spine curvature, asymmetrical muscle bulk, or strength or inability to turn the body as much in a particular direction. Malalignment syndrome is

commonly treated using biomechanical foot orthosis (BFO). It is the only form of therapy that addresses the correction of biomechanical malalignments in the lower extremity kinetic chain. The goal of treatment is the restoration of normal structure and function of the spine and pelvis; therefore, the devices used are designed to realign the body(4). However, the biomechanical effects of the orthoses used for the clinical treatment of malalignment syndrome are not completely understood. Previous studies have focused primarily on the effects of orthotic devices on foot structure rather than on the pelvis or spine in correction of malalignment syndrome. This study investigated the effect of IoT-based smart chair equipped with adjustable seat plate, pressure sensing and monitoring on spino-pelvic alignment and posture balance in the malalignment syndrome while seated.

## **Materials And Methods**

### **Patients**

From August 2017 to September 2017, a total of 30 patients with malalignment syndrome were consecutively recruited at the single institute. Diagnostic criteria of malalignment syndrome is defined as biomechanical changes, signs and symptoms (persistent foot, leg, or low back pain) consistently seen in association with 2 of these indications: rotational malalignment, upslip of the sacroiliac joint, and inflare/outflare(1). All patients provided informed consent, and the protocols involving baseline measures and contact for re-measurement were approved by the institutional review board (No 2017-07-010-006). The inclusion criteria were as follows: The volunteers of nonstructural malignment syndrome with shoulder height differences (SHDs) or iliac flea height differences (ICHDs) greater than 5 mm in radiographic images excluding participants with structural deformity. The participants within normal range with a height difference of less than 5 mm between both iliac crests are excluded from the qualitative level of the study because such cases can cause errors in the resulting measurements considering measuring errors. The exclusion criteria were as follows: patients with structural spinal deformity or who require surgery or had surgery on spine, pelvis, or hip joint, and children or elderly persons. All patients with eligible inclusion criteria were measured for baseline value. This number of patients exceeds the minimum number of cases per variable (of at least two) for five independent variables in our linear regression models(5). The 30 participants consist of 21 females and 9 males. In the 21 female participants, the average age was  $27 \pm 7$  years old (19 to 58 years old), the average height was  $161.9 \pm 5.6$  cm (150 to 173 cm), and the average weight was  $55 \pm 9.5$  kg (42 to 75 kg). In the 9 male participants, the average age was  $36 \pm 12.1$  old (19 to 50 years old), the average height was  $173 \pm 4.8$  cm (167 to 182 cm), and the average weight was  $70 \pm 14.4$  kg (50 to 98 kg).

### **Seat-interface pressure monitoring and balanced adjustment using smart chair**

Smart chair (patent No. US 10,194,754 B2) was used to measure the pressure of the buttocks in the patient's sitting position, and to balance both buttocks pressures by the left seat plate equipped with adjustable height motor (Figure 1). We analyzed the seat-interface pressure for three steps: (1) on initial

seated, (2) on balancing seated, and (3) on 1hr balancing seated. The pressure sensors that installed on each seat plates measure the seat-interface pressure applied to both the buttocks while sitting on smart chair. Then, the measured results are displayed on a mobile internet of things (IOT) device's user experience/user interface (UX/UI). Balance adjustment was performed by adjusting the height of the left seat plate; When left pressure was large, height of the left seat plate was increased (positive value adjustment). When right pressure was large, height of the left seat was lower (negative value adjustment). When adjusting the height of the left seat plate to balance both pressures, the seat-interface pressures were measured. After 1hr balancing seated, the pressure was measured again.

## **Radiographic assessment**

The anteroposterior x-ray images were obtained in the sitting and standing positions. The five spino-pelvic parameters for evaluation of smart chair were as follows: SHD, ICHD, leg length discrepancy (LLD), pelvic oblique angle (POA), and coronal imbalance (Figure 2). SHD was measured as the height difference of the soft tissue shadows directly superior to the acromioclavicular joints (positive is defined as left shoulder up/right shoulder down)<sup>(6)</sup>. ICHD and LLD values were defined as the vertical distance between 2 lines when the horizontal line is drawn from the superior aspect of the iliac crest and femoral head to the plumb line with the right angle in the anterior-posterior radiograph of the pelvis<sup>(7)</sup>. POA was defined as the angle between first line (horizontal line, HRL) and second line (pelvic coronal reference line, PCRL)<sup>(8)</sup>. Coronal imbalance was defined as a >20 mm distance between the C7 plumb line and central sacral vertical line (CSVL). It was defined as positive imbalance when the C7 plumb line passes 2cm or more to the right side of CSVL, and negative imbalance when C7 plumb line passes 2 cm or more to the left<sup>(9)</sup>.

## **Clinical trial process**

The research was conducted on 30 research participants diagnosed with malalignment syndrome, as previously defined by the Patients section. The seat-interface pressure measurements and radiographic assessments of all participants are as follows.

- 1) In radiographic images of all participants at the sitting and standing positions, the radiographic assessments were investigated.
- 2) Smart chair measured seat-interface pressure by both ischium on the parallel seat plates. The height of the left seat is adjusted to balance the left and right pressures, and then seat-interface pressures were obtained again.
- 3) The seat-interface pressure values of all participants were obtained after 1hr balancing seated. The radiographic assessments using x-ray images at the sitting and standing positions are measured

and analyzed.

## Statistical analysis

The values measured by 2 observers with more than 5 years of experience in the spine field were independently used. Intra-examiner reproducibility and inter-examiner reliability were examined using the intra- and inter-class correlation coefficients. Unbalance and balanced pressure measurements were analyzed using ANOVA test and paired t-test. All analyses were conducted using Prism version 7 (Graphpad, San Diego, USA).

## Results

### Measured seat-interface pressure before/after use of smart chair

We analyzed difference values of seat-interface pressure between left and right buttock for three steps: (1) initial seated, (2) on balancing seated, and (3) on 1hr balancing seated (Figure3). For the initial seated, the average pressure difference value was  $36.4 \pm 32.3 \Omega$  (7.00 to 153.1  $\Omega$ ). The average height of left seat was changed by  $3.7 \pm 1.7$  mm (1 to 8 mm) to balance left and right pressure, and the average pressure difference was  $15.7 \pm 20.3 \Omega$  (1.8 to 103.4  $\Omega$ ,  $p=0.003$ ) on balancing seated. The average difference values after 1hr balancing seated was  $12.7 \pm 10.9 \Omega$  (1.8 to 40.4  $\Omega$ ,  $p=0.008$ ). These results show that the pressure difference measured after an hour was improved by 65.1%.

### Spino-pelvic alignment factors in sitting position and standing position

The spino-pelvic alignment results at initial and after 1hr balancing seated are summarized in Table 1. Both the sitting and standing postures of patient were evaluated. In the initial seated with the seat plate parallel, average SHD was  $-0.9 \pm 7.1$  mm (-15.8 to 12.3 mm), and average ICHD value was  $9.5 \pm 10.0$  mm (-11.3 to 35.5 mm). After 1hr balancing seated, average SHD and average ICHD for sitting position were  $-0.8 \pm 6.6$  mm (-18.6 to 6.8 mm) and  $2.5 \pm 10.4$  mm (-24.2 to 21.1 mm), respectively. For the participants in the standing position at initial seated, average values of SHD, ICHD, LLD, POA, and coronal imbalance were  $-3.0 \pm 7.1$  mm (-17.4 to 17 mm),  $1.8 \pm 8.5$  mm (-16.5 to 16.4 mm),  $0.8 \pm 7.6$  mm (-16.8 to 13.4 mm),  $0.5 \pm 3.0^\circ$  (-6.8 to 5.0  $^\circ$ ), and  $3.5 \pm 8.2$  mm (-11.8 to 21.6 mm), respectively. After balancing seated for 1hr, average SHD, average ICHD value, average LLD, average POA, and average coronal imbalance for standing position were  $-1.0 \pm 6.3$  mm (-14.2 to 13 mm),  $0.8 \pm 7.4$  mm (-14.4 to 14.3 mm),  $0.1 \pm 6.9$  mm (-16.5 to 13.4 mm),  $0.3 \pm 2.7^\circ$  (-6.0 to 4.0  $^\circ$ ), and  $3.4 \pm 6.9$  mm (-10.0 to 18.7 mm), respectively.

The improvement of all the above measurements was statistically significant (Figure 4). In sitting position, average ICHD improved from 9.5 mm to 2.5 mm ( $p=0.037$ ), and was statistically significant. In

standing position, average values of SHD value (-3.0 mm to -1.0 mm,  $p=0.005$ ), ICHD (1.8 mm to 0.8 mm,  $p=0.016$ ), and LLD (0.8 mm to 0.1 mm,  $p=0.033$ ) improved. Figure 5 shows spino-pelvic parameters of two cases at initial and after 1hr balancing seated. In these results, SHD (-8.5 mm to -1.8 mm, 78.8%) and ICHD (from 4.5 mm to 0.7 mm, 80.8%) values improved by balanced sitting for 1hr.

## Discussion

The term 'malalignment syndrome' is considered to be a biomechanical change accompanied by signs associated with rotational malalignment of pelvis, upslip of the sacroiliac joint, and inflare/outflare of pelvis surfaces(1). Abnormal loading to pelvis that exceed this normal displacement in any direction can cause the adjoining SI joint surfaces to end up in an aberrant position so that the surfaces no longer match and stay compressed in some areas, separated in others, affecting normal movement(10). If the surfaces of SI joint become fixed or locked in an abnormal position, major consequences include dysfunction of SI joint mobility, a disturbance of the lumbo-pelvic-hip complex and its ability to transfer weight and absorb shock, and an alteration of gait(1). Deformation and degenerative changes in spinal posture cause changes in the coronal and sagittal plane arrangement and make the changes in the whole spine alignment and deformation(1, 11, 12). The arrangement of the coronal and sagittal plane involves compensatory mechanism using the change of the lower limbs and the balance of the spine-pelvis(13, 14). Change of the spinal-pelvic balance is the starting point for inducing a compensatory response that accounts for the entire spinal imbalance(13, 15). Therefore, the compensatory response of the pelvis occurs simultaneously with the change of the legs as the imbalance increases. The effect of compensatory mechanism is appeared more prevalent in the pelvis and lower extremities, and the adaptive response in the thoracic alignment is less(14, 16). However, this compensatory mechanism is also related age. In the course of 'natural cascade of degeneration', the elderly secures the stability of the spine by restabilization process including facet joint hypertrophy, bony overgrowth, and ossification of the anterior and posterior longitudinal ligament. Therefore, the older the age, it is harder to correct the spinal-pelvic imbalance by this compensatory mechanism(16). The younger the age, the faster correction of spinal pelvic imbalance is needed.

Malalignment syndrome is commonly treated using BFO treatment, the only therapy that corrects biomechanical malalignments in the lower extremity kinetic chain. The goal of this method is to restore normal structure and function of the spine and pelvis; therefore, the devices used are designed to realign the body. These orthotics increase foot stability by providing contact for weight bearing across a larger part of the sole and decrease the tendency of the feet to roll inwards or outwards after alignment has been achieved, and may decrease torque forces on legs(17). Orthotics increase sensory input from the sole surface, and the stimulation of proprioceptive receptors has been shown to help control pain. A reduced perception of pain may also elicit reflex relaxation of muscles, which may help to reduce muscle tension asymmetry(4, 18, 19). Orthotic intervention is believed to influence the pattern of lower extremity movement through a combination of mechanical control and biofeedback. Kim et al found that BFO reduce pelvic-tilt sidedness, and pelvic rotation angle asymmetry was significantly decreased in the BFO condition, compared to the barefoot and shoes conditions, which implies that BFO contributes to the

correction of pelvic rotational asymmetry(4). However, this study participant had moderate to severe pelvic asymmetry, and it remains undetermined whether BFO is effective for patients with mild pelvic asymmetry.

The starting point of the compensatory mechanism of spinal imbalance is the change of pelvis and leg position. The foot orthosis can correct the pelvis asymmetry by change the leg position. However, there is no way to correct the pelvis asymmetry by acting directly on the pelvis. Therefore, we developed a smart chair that could directly correct the imbalance of the pelvis by directly affecting the pelvic and evaluated its effectiveness. The present study described the immediate influence of smart chair on malalignment syndrome, especially with respect to change in pelvic asymmetry. This study found that pelvic asymmetry was significant decreased in the smart chair condition, which implies that smart chair contributes to the correction of pelvic asymmetry.

There were limitations in this study. First, an experimental study shows that the number of cases is not large. In patients with malalignment syndrome, recruitment was required and the recruited patients were not uniform. There were many female patients in the recruited patients. Because the malalignment syndrome itself is not a serious disease, most of the recruited patients are in the 20–30 age groups. However, the old age group is more likely to be unresponsive to the alignment correction using the smart chair because the severity of the disease is so severe that it can be irreversible in the correction of the alignment. Second, the accuracy of the parameters measured at the sitting position is poor. In the standing position, the measurement of the parameters is standardized, but the measurement is not standardized in the sitting position. In order to compensate for this problem, the Kinect posture analyzer using the optical and infrared camera was used in this study. Third, in this study, the time of applying the smart chair was one-hour, but there was no special evidence. Therefore, additional studies are needed to confirm whether 1 hour apply is really effective in correcting the alignment. The study of the degree of effect of applying over time is essential later.

## Conclusion

Spine-pelvic malalignment can be improved by individually customized pelvic compensation using balanced seat plate height adjustments under the IoT-based real-time pressure sensing and monitoring on the buttocks while seated.

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## Tables

**Table 1.** Malalignment change results in sitting position and standing position at initial and after 1hr balancing seated.

Position	Measurement of radiographic parameters	Average value		Improvement (%)	p-value
		On initial seated	1hr balancing seated		
Sitting	SHD (mm)	-0.9 ± 7.1	-0.8 ± 6.6	11.1	0.005
	ICHD (mm)	9.5 ± 10.0	2.5 ± 10.4	73.7	0.037
Standing	SHD (mm)	-3.0 ± 7.1	-1.0 ± 6.3	66.7	0.005
	ICHD (mm)	1.8 ± 8.5	0.8 ± 7.4	55.6	0.016
	LLD (mm)	0.8 ± 7.6	0.1 ± 6.9	87.5	0.033
	POA (°)	0.5 ± 3.0	0.3 ± 2.7	40.0	0.017
	Coronal imbalance (mm)	3.5 ± 8.2	3.4 ± 6.9	2.9	0.040

## Figures

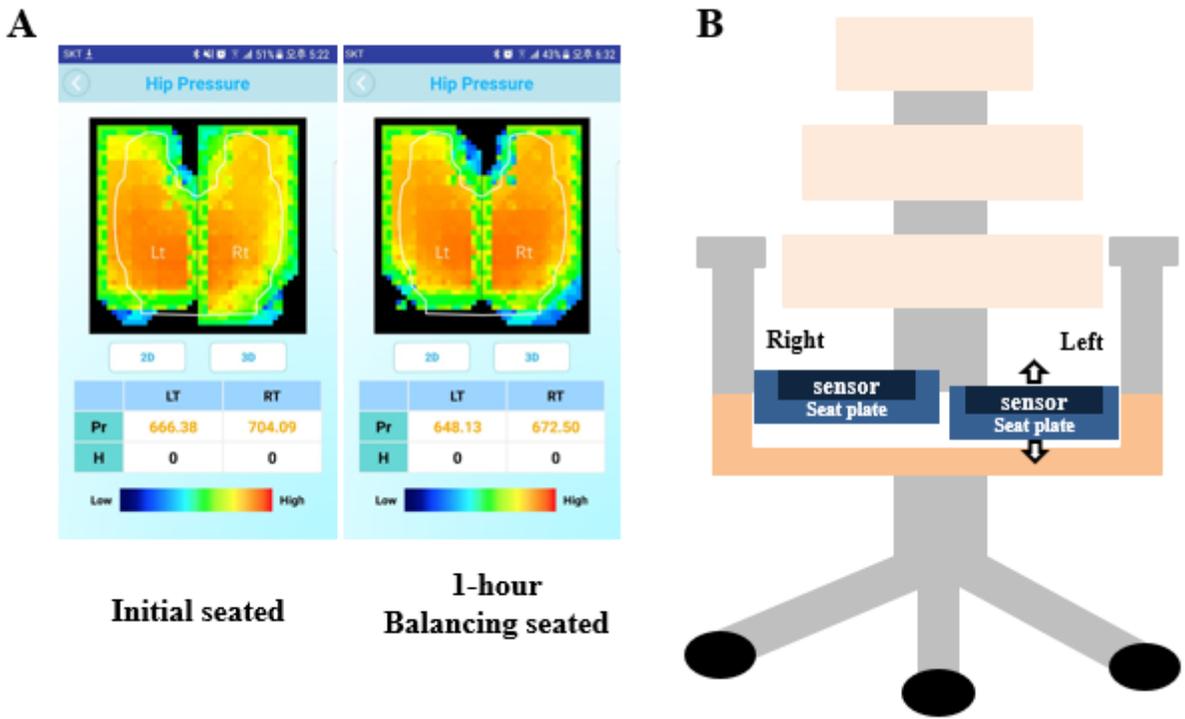
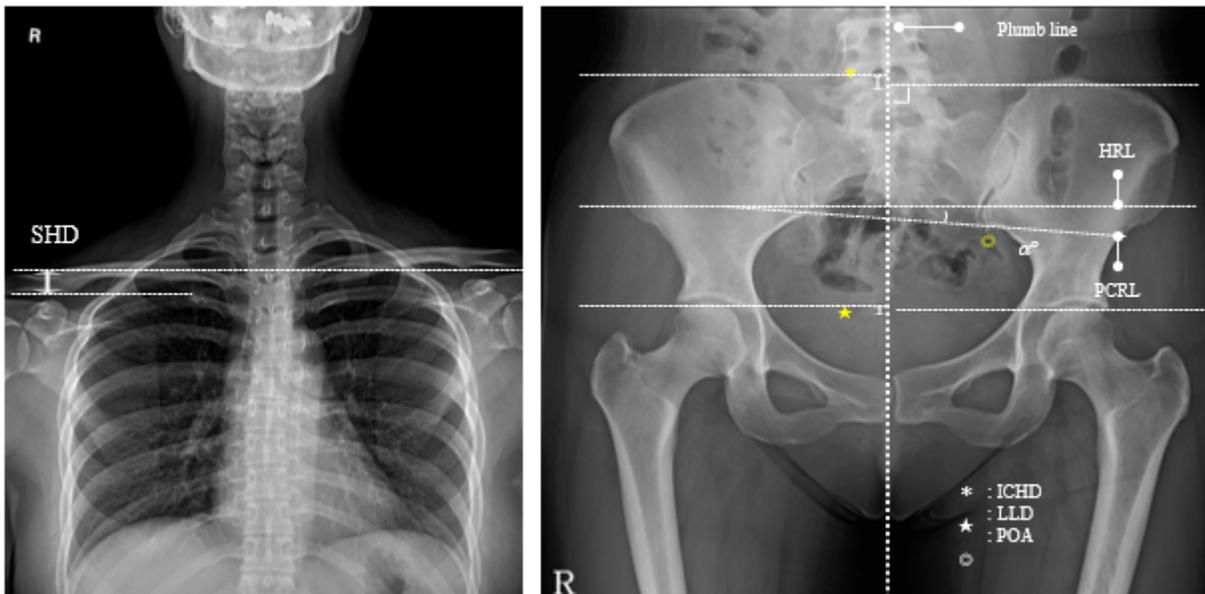


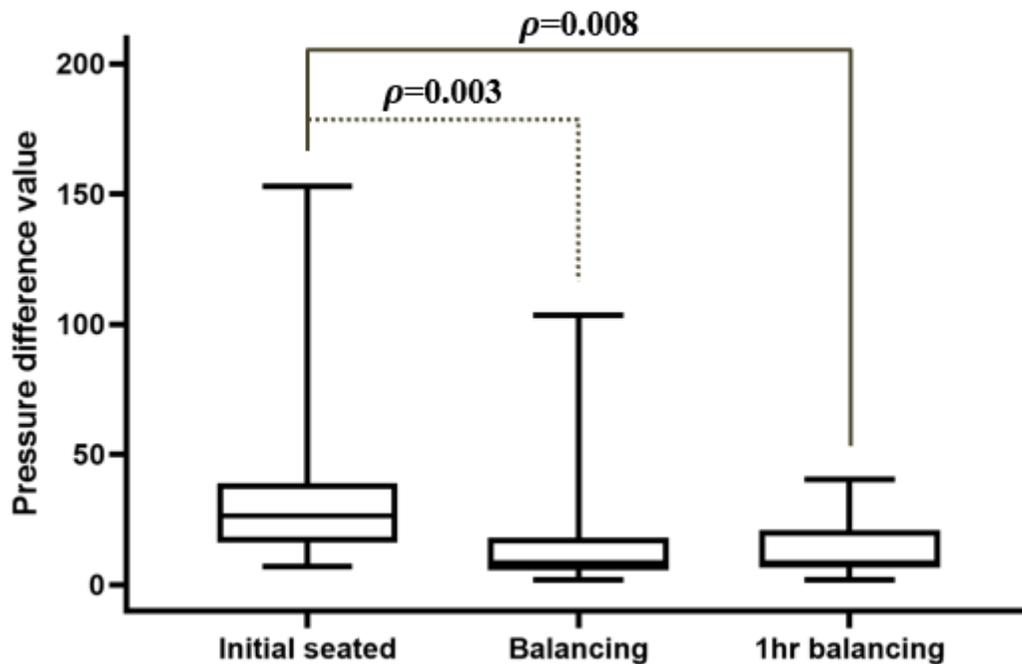
Figure 1

Measurement of ischial pressure using a smart chair; (A) User experience/user interface (UX/UI) display image for ischial pressure measurement. Initial unbalanced pressure was 666.38 to 704.09, a difference of 37.71, followed by a 1mm lower left seat plate for balancing, and improved pressure changes during one-hour balanced seating (648.13 vs 672.50, a difference of 24.37). (B) Diagram of the smart chair using adjustable seat plate equipped with pressure sensor. Only left seat plate is adjustable height for balanced pressure distribution.



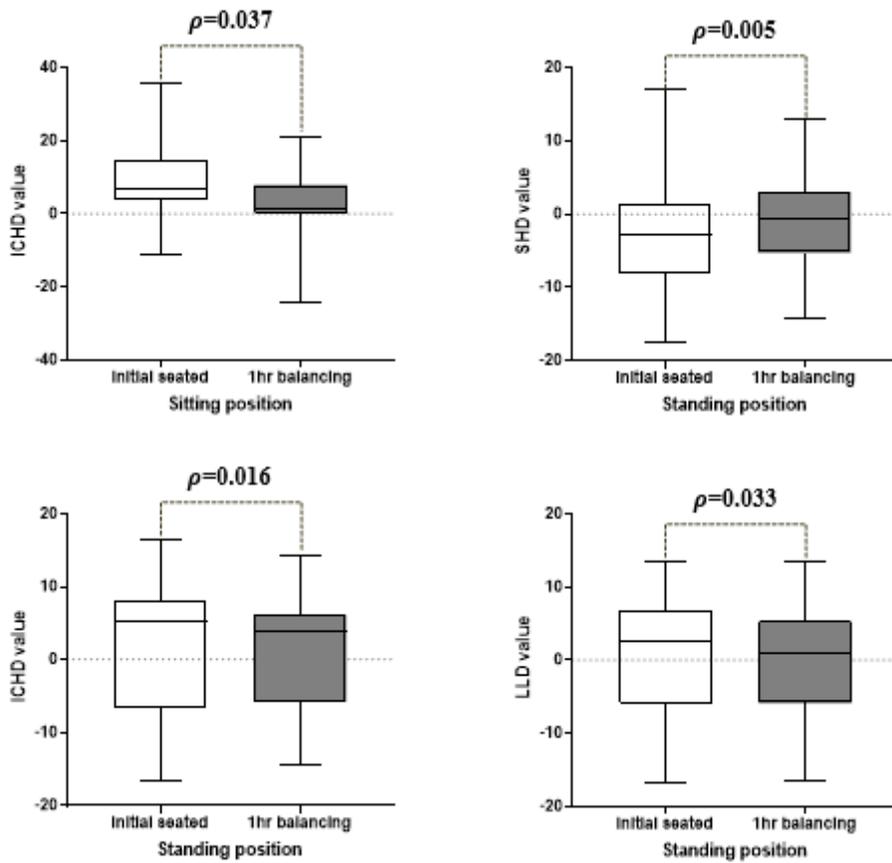
**Figure 2**

Evaluation of radiographic parameters for spino-pelvic imbalance measurement on coronal image: shoulder height differences (SHD), iliac crest height differences (ICHD), leg length discrepancy (LLD), and pelvic oblique angle (POA); angle(@) between horizontal line (HRL) and pelvic coronal reference line (PCRL)



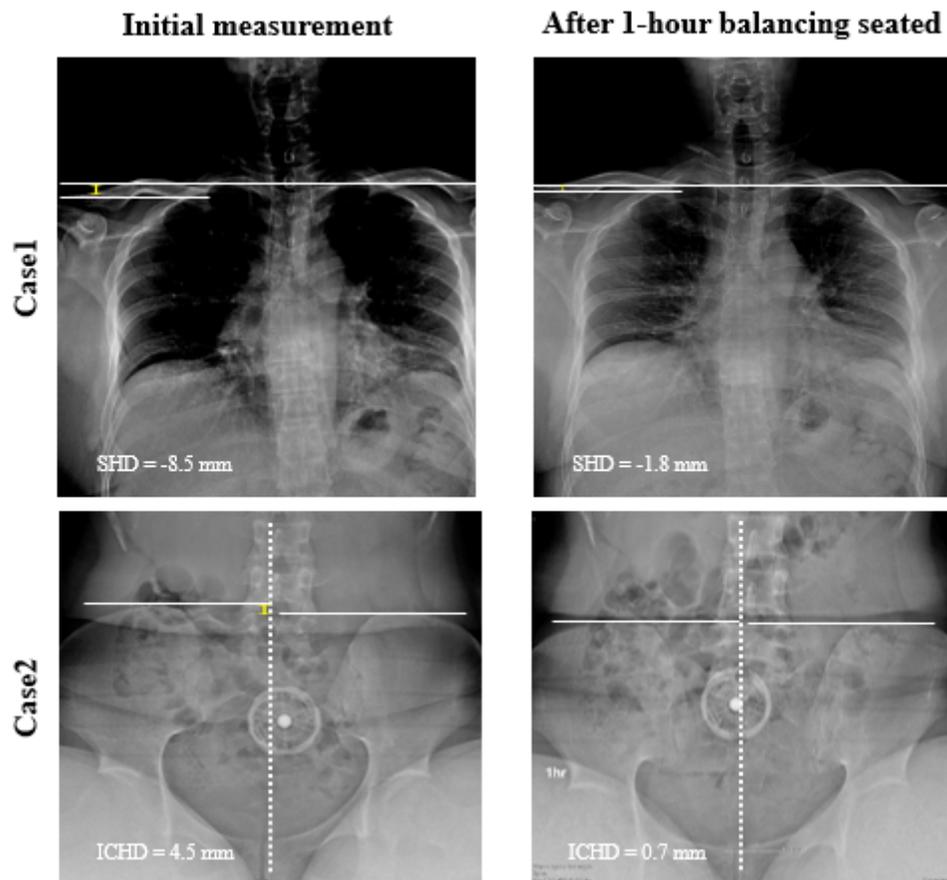
**Figure 3**

Comparison of difference values in seat-interface pressure between left and right buttock measured from the three steps: on initial seated, on balancing seated, and on 1hr balancing seated. The average pressure difference value was  $36.4 \pm 32.3 \Omega$  for initial seating,  $15.7 \pm 20.3 \Omega$  on subsequent balanced seating, and  $12.7 \pm 10.9 \Omega$  on 1hr balancing seated, demonstrating statistically significant improvements among the steps ( $p=0.003, 0.008, \text{ANOVA}$ ).



**Figure 4**

Compare the changes of the spino-pelvic parameters in sitting and standing position at initial and after 1hr balancing seated. In sitting position, the average ICHD value was statistically significant improvement from  $9.5 \pm 10.0$  mm at initial seating to  $2.5 \pm 10.4$  mm for 1hr balancing seated ( $p=0.037$ ). The standing position also showed statistically improvements with average SHD value ( $-3.0$  mm to  $-1.0$  mm,  $p=0.005$ ), average ICHD value ( $1.8$  mm to  $0.8$  mm,  $p=0.016$ ) and average LLD value ( $0.8$  mm to  $0.1$  mm,  $p=0.033$ ) by paired t-test.



**Figure 5**

The measurement of radiographic parameters on initial and 1hr balancing seated. The SHD value was improved from -8.5 mm on initial seated to -1.8 mm on 1hr balancing seated (case 1). In case 2, the measurement of the ICHD value improved from 4.5 mm to 0.7 mm during 1hr balancing seated.