Evaluation for Postural Balance Pattern of Patients with Adolescent Idiopathic Scoliosis using Pressure Sensor Systems

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Abstract. Abnormal lateral curvature of the spine may affect postural balance pattern in static and dynamic condition. Previous studies demonstrated asymmetrical balance patterns of adolescent patients with idiopathic scoliosis during sitting and walking. However, pressure distribution data have been rarely used to analyze asymmetrical postural pattern of scoliotic patients. In this study, pressure data analysis for evaluation of postural balance in patients with idiopathic scoliosis was conducted by utilizing two types of pressure sensor systems. Subjects were classified into a control group, scoliosis with left convex side of the curve group, and scoliosis with right convex side of the curve group. All subjects were instructed to walk and sit on pressure sensor systems which is consist of a lot of capacitive sensors. Pressure distribution data were subdivided into two regions of masks and analyzed for maximum force, peak pressure, and contact area. There were significant differences in pressure distribution patterns between scoliosis patient groups according to the direction of the curve during walking and sitting. From these results, it was concluded that idiopathic scoliosis cause postural asymmetry and unequal weight distribution during walking and sitting. Furthermore, pressure sensor systems can be used to detect asymmetrical balance and postural change of patients with idiopathic scoliosis and provide accurate diagnosis and rehabilitation method for individuals.

Introduction

Postural balance is the ability to keep the line of gravity of a body within the base of support. The ability to keep balance is one of the most essential factors in activities of daily living. Human body tries to maintain its correct posture under static and dynamic conditions against gravity. Good posture provides normal biomechanical functions of the musculoskeletal system. However, improper postural alignment and trunk stability including asymmetrical pelvic tilt in the three different planes (frontal, sagittal, and transverse) and excessive curvature of the spine such as lordosis, kyphosis, and scoliosis can cause spinal deformities as well as influence on our balance system negatively. Previous studies discovered that abnormalities in balance function caused by progressive curve were found to be associated with pelvic deformities in the sagittal and frontal plane [1].

Scoliosis is a three-dimensional deformity defined as an abnormal lateral curvature of the spine. It is divided into two categories: congenital and idiopathic. Congenital is caused by vertebral anomalies
present at birth and idiopathic means the identifying cause of the disease is unknown. Idiopathic scoliosis is defined by the age of onset such as infantile, juvenile, and adolescent. Generally, curve types of scoliosis are classified as C-shaped and S-shaped based on the direction and location of the curve in spinal deformity. C-shaped and S-shaped curves refer to a single and double curve, respectively, in the thoracic, lumbar, or thoracolumbar region. These curve types are connected to asymmetrical rotation, elevation, and tilting of the pelvis which can cause various pain-related symptoms.

Adolescent idiopathic scoliosis (AIS) is the most common type that is present in 2 to 4 % of children between the ages of 11-17 years [2]. More severe curve that requires treatment is present more frequently in females than males. Initial asymmetry of the body during growth phases may affect progression of AIS. Progressive curve is related to posture asymmetry, and it can affect physical activity in adolescent. Scoliosis in adolescent has been closely associated with excessive spinal curvature, asymmetrical load on the spine, and progressive loss of both trunk and lower limb balance [3]. In biomechanics, the trunk and pelvis plays a fundamental role in the maintenance of body balance. Therefore, convexity and concavity of the spinal curve with pelvic inequality would alter the postural balance pattern in standing, sitting, and during walking. The scoliosis patients group displayed increasing displacement of the center of pressure (COP) and the center of mass (COM) excursion [4]. Aggravated scoliosis with pelvic imbalance leads to increasing several trunk muscle contraction, postural instability, and asymmetrical tilting angle while standing and sitting [5,6]. Shamberger [7] described the connection between asymmetrical alignment of the lower extremities and compensatory curvatures of the spine. Additionally, patients with idiopathic scoliosis showed asymmetrical gait in kinematic and ground reaction force (GRF) due to changes in postural control strategies [8].

To date, many studies related to postural balance of idiopathic scoliosis in adolescent have been conducted by utilizing various balance assessment systems. Muscle imbalance in the lumbar or thoracolumbar area on the convex side of patients with idiopathic scoliosis was observed by measuring electromyography (EMG) signals in thoracic, lumbar, and abdominal trunk muscles [9]. More reduced step length, pelvis, hip, and shoulder frontal motion, hip transversal motion, knee sagittal motion of scoliosis patients than normal subjects was observed by using three-dimensional motion analysis equipment [10]. However, pressure distribution data have been rarely used to analyze asymmetrical postural pattern of scoliotic patients in the literature. It is crucial to assess the pressure distribution pattern for patients with idiopathic scoliosis because pressure distribution data is useful to get the quantitative information about normal or abnormal balance pattern for individuals in static and dynamic conditions. In addition, in recent years, adolescent students spend most of time sitting with the increase in sedentary activities such as studying, watching television, and playing computer game. Bennett [11] reported that patients with AIS have muscular imbalance between concave and convex side of the spine as they spend most of time sitting. Accordingly, there is need to investigate the weight distribution pattern of AIS patients during sitting and effect of sitting balance control on body balance system during gait.

Pressure sensors are commonly used in various medical fields to provide the information about postural balance of patients by converting electric signal into physical output. There are many pressure measurement methods including resistive, inductive, capacitive, and piezoelectric for measuring pressure between two contacting surfaces. Especially, capacitive sensors are more suitable than other sensors for assessing interface pressure due to its advantage of high sensitivity and linear characteristics. Platform system with capacitive sensors has been utilized to collect pressure distribution of the foot during walking [12]. In addition, capacitance mapping system was used to analyze the effect of the body asymmetry, trunk mobility, postural change caused by prolonged sitting in working conditions on spinal deformity [13].

The purpose of this study was to assess the postural balance pattern of AIS patients and to analyze the correlation between compensatory strategies of subjects during sitting and walking by utilizing two types of pressure sensor systems based on capacitive sensors.
Methods

Subjects

Eighteen adolescents were recruited from the Department of Rehabilitation Medicine of Chungnam National University Hospital in Daejeon, South Korea. Subjects were consisted of three groups as shown in Fig. 1. The control group (CG) consisted of 6 adolescents without spinal deformation, previous history of injury, and abnormal gait pattern. The scoliosis patient group was divided into two subgroups according to the direction of the curve in scoliosis: scoliosis group 1 (SG 1) and scoliosis group (SG 2). The inclusion criteria for scoliosis patients were anteroposterior (AP) full spine standing X-ray evidence of idiopathic scoliosis with a C-shaped lumbar or thoracolumbar curve and no previous conservative or surgical treatment for the scoliosis. The SG 1 consisted of 6 adolescents with the left convex side of the curve and SG 2 consisted of 6 adolescents with the right convex side of the curve.

![Fig. 1. (a) Control group; (b) Scoliosis group 1; (c) Scoliosis group 2](image)

All adolescents and their parents provided written informed consent prior to their voluntary participation. Characteristics of subjects about demographic data including mean age, height, body weight, body mass index (BMI), and Cobb angle are shown in Table 1.

<table>
<thead>
<tr>
<th>Table 1 Characteristics of subjects</th>
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<tbody>
<tr>
<td>Control group (mean±SD) (n = 6)</td>
</tr>
<tr>
<td>Scoliosis patients (mean±SD)</td>
</tr>
<tr>
<td>(Group 1 n = 6)</td>
</tr>
<tr>
<td>(Group 2 n = 6)</td>
</tr>
<tr>
<td>Age (years) 15.17±2.04</td>
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<tr>
<td>Height (cm) 166.17±7.78</td>
</tr>
<tr>
<td>Body weight (kg) 62.51±5.40</td>
</tr>
<tr>
<td>BMI (kg/m²) 22.87±2.09</td>
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<td>Cobb angle (°) -</td>
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</table>

Pressure Sensor System
Two types of pressure sensor systems were utilized to detect postural balance of AIS patients during walking and sitting, as shown in Fig. 2. The emed-at platform (Novel Gmbh, Munich, Germany) is a plantar pressure measurement system. This system contains 1,760 capacitive sensors with an individual sensor area of 0.25 cm² in an array to determine the local loading on the foot during walking. The dimension of the platform were 610 mm × 323 mm × 18 mm with a sensor dimension of 389 mm × 226 mm, at a sampling rate of 50 Hz. Sitting balance was assessed by using Pliance seat sensor system (Novel Gmbh, Munich, Germany). It is consists of a flexible 256 capacitive sensors with an individual sensor area of 1.5 cm² in a matrix configuration for measuring weight distribution of the body during sitting. The dimension of the sensor mat were 150 mm × 100 mm × 40 mm with a sampling frequency of 100 Hz in a matrix configuration for measuring weight distribution of the body during sitting.

Procedure

Subjects were instructed to walk over the plantar pressure measurement system which is embedded in the floor by using the two-step protocol [14] and to sit in the usual manner on the capacitive seat sensor system with arms crossed on contra-lateral shoulder for 30 seconds. Plantar pressure measurement system starts recording automatically when the subject’s foot touches the platform. Seat sensor system was located on the unstable board (length: 335 mm, width: 305 mm, height: 36 mm). The curvature radius of the board was 320 mm. Symmetrical or asymmetrical postural pattern of patient can be detected by its unstable structure. This unstable structure has been used to assess the ability of postural control of the spine in the frontal and sagittal plane while sitting [15]. Additionally, a foot support was employed to adjust the knee and ankle at 90° to prevent leg movements.

Data analysis

Pressure distribution data were subdivided into two regions of masks (left and right side) and analyzed for maximum force, peak pressure, and contact area by using Novel software (Novel Gmbh, Munich, Germany). Plantar pressure distribution and body weight distribution data was displayed in 2D and 3D, and the pressure values are shown according to the corresponding color scale.

Statistical analysis was conducted using SPSS PASW statics 18 software (SPSS Inc, Chicago, USA). A t-test was used to examine the differences in pressure distribution between left and right side, at the p < .05 level. Comparisons were also made for measured variables in experimental results between the groups by using one-way ANOVA with Post Hoc Scheffé test, at the p < .05 level.

Results

Comparisons of plantar pressure distribution between the groups are presented in Table 2. Maximum force, peak pressure, and contact area of the SG 1 increased on the left side, while plantar pressure distribution of the SG 2 decreased on the right side during gait. There were no significant
differences in the maximum force and peak pressure between both sides or between the groups. However, contact area between the left and right side of SG 1 was only different significantly (p < 0.05).

Table 2 Differences in plantar pressure distribution between the groups

<table>
<thead>
<tr>
<th></th>
<th>Left</th>
<th>Right</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum Force</td>
<td>760.01±114.09</td>
<td>763.18±98.73</td>
<td>0.929</td>
</tr>
<tr>
<td>Plantar Peak</td>
<td>558.06±140.94</td>
<td>559.44±108.22</td>
<td>0.974</td>
</tr>
<tr>
<td>Plantar Pressure</td>
<td>463.61±108.01</td>
<td>442.22±104.86</td>
<td>0.551</td>
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</table>

Table 3 Differences in body pressure distribution between the groups

<table>
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<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum Force</td>
<td>205.45±38.74</td>
<td>206.90±36.51</td>
<td>0.908</td>
</tr>
<tr>
<td>Plantar Peak</td>
<td>46.71±15.73</td>
<td>45.31±15.42</td>
<td>0.789</td>
</tr>
<tr>
<td>Plantar Pressure</td>
<td>39.31±15.94</td>
<td>35.85±19.27</td>
<td>0.561</td>
</tr>
</tbody>
</table>

Comparisons of body pressure distribution between the groups are presented in Table 3. Maximum force, peak pressure, and contact area of the SG 1 increased on the left side, while plantar pressure distribution of the SG 2 decreased on the right side during sitting. There were no significant differences in the maximum force and contact area between both sides or between the groups. However, peak pressure between the left and right side of SG 2 was only different significantly (p < 0.05).

Table 3 Differences in body pressure distribution between the groups

<table>
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M±SD, *p-value < .05

Figure 3 illustrates the differences in plantar pressure distribution between the groups by using 2D and 3D display mode. As compared with plantar pressure among CG, SG 1, and SG 2, pressure
distribution pattern of SG 1 and SG 2 were tilted in accordance with their direction of scoliosis curve, respectively.

![Graph showing differences in 2D and 3D plantar pressure distribution between the groups.](image)

**Fig. 3. Differences in 2D and 3D plantar pressure distribution between the groups**

Figure 4 illustrates the differences in body pressure distribution between the groups by using 2D and 3D display mode. As compared with body pressure among CG, SG 1, and SG 2, pressure distribution pattern of SG 1 and SG 2 were tilted in accordance with their direction of scoliosis curve, respectively.
Conclusion

In this study, postural balance pattern of patients with idiopathic scoliosis in adolescent was evaluated by using pressure measurement system based on capacitive sensors. Progressive idiopathic scoliosis would alter the postural balance pattern during sitting. We hypothesized that altered sitting postural balance caused by abnormal lateral curvature of the spine may affect the plantar pressure distribution during gait. Generally, scoliosis patients with C-shaped curve tend to have more severe thoracolumbar spinal imbalance than patients with S-shaped curve [16]. Accordingly, we focused on patients with C-shaped lumbar or thoracolumbar curve and classified into two groups according to direction of scoliosis curve. Scoliosis patients group with left convex side of the curve showed more tilted plantar and body pressure distribution to the left side than the right side. In contrast, plantar and body pressure of scoliosis patients group with right convex side of the curve increased on the right side. It means that direction of scoliosis curve may affect directly the asymmetrical pressure pattern during walking and sitting. These asymmetrical patterns are connected to significant difference in the contact area and peak pressure of scoliosis patients in accordance with their characteristic of spinal curve. From the results of this study we confirmed that AIS have influence on postural imbalance and control problem in walking and sitting conditions.

It has been reported that unbalanced pressure distribution can cause pressure ulcers and advance deformation of the spine. Therefore, studies about postural balance in patients with AIS have been emphasized by other investigators. Measurement of balance abnormalities in adolescents with idiopathic scoliosis is very important to prevent progression of the curve and to treat pain caused by spinal deformities.
Postural balance pattern of scoliosis patients with lumbar or thoracolumbar curve were analyzed by using plantar and body pressure measurement system. Asymmetrical pressure distribution pattern was caused by direction of scoliosis curve during walking and sitting. These asymmetrical patterns are connected to significant difference in pressure distribution between scoliosis patient groups in accordance with their characteristic of spinal curve. Consequently, it was concluded that idiopathic scoliosis in adolescent can have a significant effect on postural balance and pressure distribution. Furthermore, this paper suggested that pressure sensor systems which is consist of a lot of capacitive sensors with high sensitivity and linear characteristics can provide accurate information about postural balance of patients with idiopathic scoliosis and can be utilized to prevent progression of postural asymmetry caused by abnormal lateral curvature of the spine by measuring plantar and body pressure of patients during walking and sitting.

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References


