Analysis of the foot pressure distribution for scoliotic patients using an instrumented treadmill

Ji-Yong Jung[1], and Jung-Ja Kim[1,2,*]
[1]Division of Biomedical Engineering, College of Engineering,
Chonbuk National University
567, Baekje-daero, Deokjin-gu, Jeonju-si, Jeollabuk-do, 54896
Republic of Korea
cholbun@hanmail.net
[2]Research Center of Healthcare & Welfare Instrument for the Aged,
Chonbuk National University
567, Baekje-daero, Deokjin-gu, Jeonju-si, Jeollabuk-do, 54896
Republic of Korea
jungjakim@jbnu.ac.kr

Abstract: - The purpose of this study was to investigate the foot pressure distribution pattern of patients with idiopathic scoliosis using an instrumented treadmill. 14 subjects were participated in this study and divided into two groups according to the curve direction. All subjects were asked to walk on a treadmill for 1 minute at a speed of 4.0 km/h. To analyze the variation of the foot pressure distribution, all data were classified with four stages of the stance phase: loading response, mid-stance, terminal stance and pre-swing phase. The opposite tendency was observed in the foot pressure distribution between two groups. In addition, significant differences in the force between the convex and concave side were presented at mid-stance and terminal stance phase. From these results, it was suggested that the direction of the scoliotic curve can influence on dynamic foot pressure distribution and postural balance. Furthermore, an instrumented treadmill can be utilized to assess gait mechanism as well as to monitor the progression of exercise program for scoliotic patients in rehabilitation medicine.

Key-Words: - Idiopathic scoliosis, foot pressure distribution, instrumented treadmill, gait, postural balance

1 Introduction

Scoliosis is a three-dimensional spinal deformity which involves lateral curvature and vertebral rotation. Idiopathic scoliosis is the most common type which accounts for up to 80 % of all scoliosis patients [1]. However, until now, the definitive etiology of idiopathic scoliosis remains unknown. Untreated idiopathic scoliosis could be linked to abnormal curvature of the spine in the adult [2]. Most scoliotic curve develops in the thoracic and lumbar area. And, it can be classified into four curve types such as thoracic curve, lumbar curve, thoracolumbar curve and double curve.

Spine plays a major role in maintaining stable postural balance during both static and dynamic conditions. Postural changes caused by spinal curvature which affects the body alignment can alter locomotion pattern [3]. The asymmetrical pressure distribution induced by spine deformation have been associated with poor body balance during walking. Previous studies analyzed gait characteristics in participants with scoliosis by utilizing force plates and 3D motion analysis equipment. Abnormal vertebrae morphology in patient with scoliosis would alter the center of mass (COM) while walking [4]. Scoliotic patients were shown to have decreased step length, gait velocity, and range of motion (ROM) in the lower extremities [5-6]. Significant gait asymmetry in the vertical [3], anterior-posterior, and medial-lateral [7] directions has been related to pathological gait pattern of scoliotic patients.

Continuous analysis of foot pressure distribution variation during walking is one of the most crucial factors to understand correlation between gait asymmetry and spinal deformity. However, foot pressure data have been rarely used in previous literatures. It is necessary to assess quantitative foot pressure data for evaluating gait mechanism and balance function of patient with idiopathic scoliosis.

The gait analysis on a treadmill has been conducted due to it can provide standardized experimental conditions according to the purpose of research [8-9]. Although the increasing use of instrumented treadmills in various clinical research fields, foot pressure distribution variation during the stance phase using an advanced instrumented treadmill which contains a pressure sensor matrix has not been investigated.

Therefore, the aim of this study was to investigate the gait characteristics of patient with idiopathic scoliosis by measuring foot pressure distribution during walking on instrumented treadmill.

2 Method

2.1 Subjects

Fourteen subjects who were diagnosed idiopathic scoliosis participated in this study. The inclusion criteria for subjects were posteroanterior (PA) full spine standing X-ray evidence of idiopathic scoliosis with 4cp (major thoracolumbar or lumbar curve with shifted pelvic block to the opposite side of the major curve) type based on Schroth classification. Subjects were excluded if they had previous conservative or surgical treatment for the scoliosis, gait abnormalities, spinal disorder, and physical disability. Subjects were divided into two groups: the scoliosis with left thoracolumbar curve group (LTLCG) and the scoliosis with right thoracolumbar curve group (RTLCG), as shown in Fig. 1. All subjects gave written informed consent regarding the experimental protocol which was approved by Institutional Review Board of Chonbuk National University. The mean age, height, body weight, and Cobb angle of two groups are shown in Table 1.

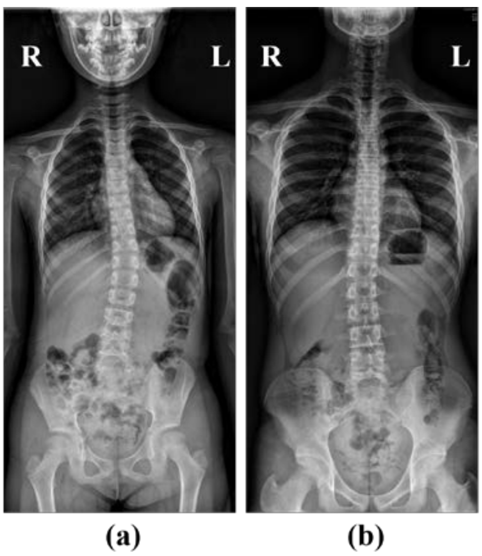

Fig. 1. (a) Scoliosis with left thoracolumbar curve group (LTLCG), (b) Scoliosis with right thoracolumbar curve group (RTLCG)

Table 1. Characteristics of subjects (Mean±SD)

	LTLCG	RTLCG
Age (years)	23.42±2.88	24.57±0.98
Height (cm)	167.01±8.56	170.93±5.79
Body weight (kg)	56.14±5.55	64.43±9.74
BMI (kg/m^2)	20.15±1.63	21.99±2.54
Cobb angle (°)	11.5±2.93	12.06±2.29

2.2 Protocol

Before the experiment, subjects walked for 5 minutes for warm up and to adapt step speed. And then, all subjects performed 1-min walking trials on the instrumented treadmill at a speed of 4.0 km/h, and took a 5 minute break between trials in order to prevent fatigue.

The foot pressure distribution data were recorded within the software. These data were classified with four stages of the stance phase: loading response phase (0-10 %), mid-stance phase (10-30 %), terminal stance phase (30-50 %) and pre-swing phase (50-60 %).

2.3 Apparatus

The Foot pressure distribution was assessed with the Zebris FDM-T Treadmill (Zebris Medical GmbH, Isny, Germany), as shown in Figure 2. This instrumented treadmill consists of a treadmill ergometer with an integrated pressure sensor mat which comprising a capacitance-based sensor matrix. The sensor plate had a sensing area of 94.8 × 40.6 cm and comprised 5,379 sensors. The treadmill had a walking surface of 150 × 50 cm and its speed can be adjusted from 0.2 to 24 km/h in 0.1 km/h steps. Dynamic foot pressure distribution while walking on the treadmill was recorded by the sensors at a sampling rate of 100 Hz.

2.4 Statistical analysis

Statistical analysis was performed using SPSS statistical software (SPSS Inc, Chicago, USA). All data were first tested for normality using the Shapiro-Wilk test. An independent t-test was used to compare the differences in foot pressure distribution between the convex and concave side, at $p < 0.05$ and $p < 0.01$ level, respectively.

3 Results

The foot pressure distribution variations between left and right side of two groups, during the stance phase, are shown in Fig. 3. There were contrary patterns in the foot pressure distribution between two groups. The maximum force was presented at terminal stance phase in both groups. In LTLCG, the force increased in the concave side (right side) at

Fig. 2. Instrumented treadmill

loading response and pre-swing phase while it increased in the convex side (left side) at mid-stance and terminal stance phase. When compared the overall tendency of force variations during the stance phase, in RTLCG, the force also increased in the concave side (left side) at loading response and pre-swing phase while it increased in the convex side (right side) at mid-stance and terminal stance phase. Significant differences in force between the left and right side were shown in the stance phase except loading response phase ($p < 0.05$ and $p < 0.01$, respectively).

4 Discussion

This study presents the gait characteristic of patient with idiopathic scoliosis based on the results in foot pressure distribution during the stance phase on instrumented treadmill.

The results shows that the force in the concave side for both scoliotic patient groups was greater than the convex side at loading response and pre-swing phase. The loading response phase begins with initial floor contact. In this phase, the body weight is transferred onto the forefoot with flexed knee for shock absorption. The pre-swing phase begins with initial contact of the contralateral limb. And then, with ipsilateral toe-off, the abrupt body weight is transferred during the swing phase [10]. The motions of the trunk have been associated with other body segments including pelvis, hip, knee, and ankle during gait. And, there was a correlation between the asymmetrical trunk motion to the concave side and the pelvis during walking [11]. These increased force patterns in the concave side at loading response and pre-swing phase could be related to decreased walking speed induced by shorter stride length and longer stride time [12].

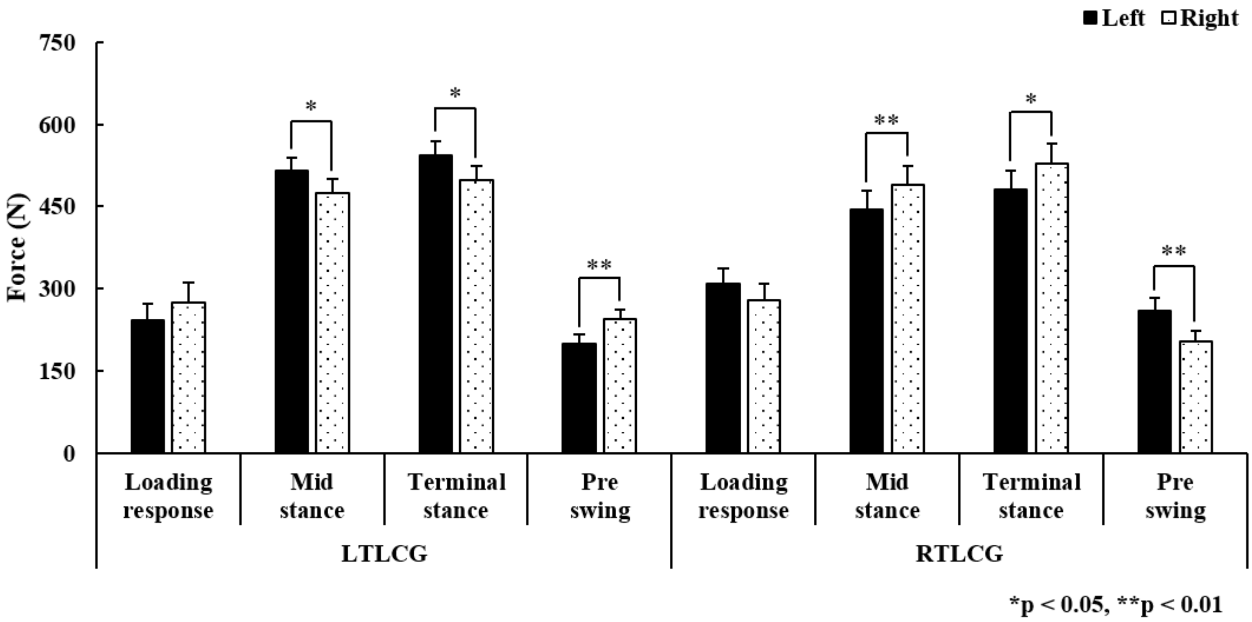

Fig. 3. Differences in the force between the left and right side of two scoliotic patient groups

The mid-stance and terminal stance phase is the first sub-phase of single limb support. In these phases, the foot flattens on the ground to provide stable support while moving forward with body weight shifts. Previous research discovered that increased asymmetrical foot loading was connected with the curve direction of scoliotic patients. Altered pelvis rotations related to the curve directions could influence on the foot pressure distribution during the mid-stance and terminal stance phase [13]. In addition, patients with scoliosis tend to support extra loading relevant to the convex side of the scoliosis curve [14]. On the contrary to the results during the pre-swing and loading response phase, the force in the convex side increased significantly during the mid-stance and terminal stance phase. These results is consistent with the previous research that showed direction of the curve in idiopathic scoliosis may cause unequal foot pressure distribution which is associated with asymmetrical gait pattern during the stance phase.

5 Conclusion

This study shows that the direction of the scoliotic curve could influence gait strategies which involves increased foot pressure distribution patterns in the convex and concave side during the stance phase. Furthermore, the foot pressure information obtained with the instrumented treadmill can be used to measure and analyze the foot pressure distribution for understanding gait characteristics and dynamic postural balance patterns of patient with idiopathic scoliosis.

Acknowledgement

This research was supported by the Basic Science Research Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Science, ICT & Future Planning (NRF-2016R1A2B4015623).

References:

[1] K. Hume, Scoliosis: to screen or not to screen, *Br J Sch Nurs*, Vol. 3, No. 5, 2008, pp. 214-218.

[2] J. M. Buchowski, Adult scoliosis: etiology and classification, *Seminars in Spine Surgery,* Vol. 21, No. 1, 2009, pp. 2-6.

[3] K. W. Wu, T. M. Wang, C. C. Hu, S. W. Hong, P. A. Lee, and T. W. Lu, Postural adjustments in adolescent idiopathic thoracic scoliosis during walking, *Gait Posture*, Vol. 68, 2019, pp. 423-429.

[4] J. H. Yang, S. W. Suh, P. S. Sung, and W. H. Park, Asymmetrical gait in adolescents with idiopathic scoliosis, *Eur Spine J*, Vol. 22, No. 11, 2013, pp. 2407-2413.

[5] P. Mahaudens, C. Detrembleur, M. Mousny, and X. Banse, Gait in adolescent idiopathic scoliosis: energy cost analysis, *Eur Spine J*, Vol. 18, No. 8, 2009, pp. 1160-1168.

[6] P. Mahaudens, X. Banse, M. Mousny, and C. Detrembleur, Gait in adolescent idiopathic scoliosis: kinematics and electromyographic analysis, *Eur Spine J*, Vol. 18, No. 4, 2009, pp. 512-521.

[7] N. Chockalingam, P. H. Dangerfield, A. Rahmatalla, N. Ahmed el, and T. Cochrane, Assessment of ground reaction force during scoliotic gait, *Eur Spine J*, Vol. 13, No. 8, 2004, pp. 750-754.

[8] P. Terrier, and O. Dériaz, Kinematic variability, fractal dyanmics and local dynamic stability of treadmill walking, *J Neuroeng Rehabil*, Vol. 8, 2011.

[9] P. Terrier, Step-to-Step variability in treadmill walking: influence of rhythmic auditory cueing, *PLoS ONE*, Vol. 7, No. 10, 2012.

[10] A. Kharb, V. Saini, Y. K. Jain, and S. Dhiman, A review of gait cycle and its parameters, *Int J Comp Eng Man*, Vol. 13, 2011, pp. 78-83.

[11] I. A. Kramers-de Quervain, R. Muller, A. Stacoff, D. Grob, and E. Stussi, Gait analysis in patients with idiopathic scoliosis, *Eur Spine J*, Vol. 13, No. 5, 2004, pp. 449-456.

[12] C. K. Haber, and M. Sacco, Scoliosis: lower limb asymmetries during the gait cycle, *Arch Physiother*, Vol. 5, 2015.

[13] J. Y. Jung, S. K. Bok. B. O. Kim, Y. W, and J. J. Kim, Evaluation for postural balance pattern of patients with adolescent idiopathic scoliosis using pressure sensor systems, *Proc. Int. Conf. on Mechanics, Materials, Mechanical Engineering & Chemical Engineering*, 2015, pp. 138-146.

[14] A. V. Bruyneel, P. Chavet, G. Bollini, and S. Mesure, Gait initiation reflects the adaptive biomechanical strategies of adolescents with idiopathic scoliosis, *Ann Readapt Med Phys*, Vol. 53, 2010, pp. 372-386.