Int J Clin Exp Med 2019;12(7):8901-8907
www.ijcem.com /ISSN:1940-5901/IJCEM0088619

Original Article

Investigation of center of pressure velocity characteristics for scoliosis during walking

Yao Meng[1], Minjun Liang[1,2], Lin Fu[1], Feng Ren[1], Gusztáv Fekete[3], Yaodong Gu[1,2]

[1]Faculty of Sports Science, Ningbo University, Ningbo, China; [2]Research Academy of Grand Health, Ningbo University, Ningbo, China; [3]Faculty of Informatics, Eötvös Loránd University, Hungary

Received November 19, 2018; Accepted April 10, 2019; Epub July 15, 2019; Published July 30, 2019

Abstract: The goal of this study was to measure the spatial-temporal gait parameters characteristics of scoliosis subjects (I-observation and II-brace), including joint motion, COP velocity, and percentage of stance phase (heel strike, mid-stance, terminal stance). Spines of sixteen subjects were measured by using DIERS Formetric 4D and divided them into two groups averagely, eight for observation, and eight for brace. The joints angles of ankle and hip were collected by VICON, and the COP velocity was calculated at each period of stance phase. II showed greater ankle dorsiflexion, hip extension and abduction than I. COP velocity of I presented larger than II during the mid-stance phase, but less during the heel strike phase. Compared to I, II showed greater ankle dorsiflexion associated with ankle stability. Low back pain also may be cause by hip abduction, it could be a risk to worsen spine deformation.

Keywords: Scoliosis, DIERS Formetric 4D, kinematics, COP velocity

Introduction

Scoliosis is defined as a lateral curvature of the spine, which is common in humans. Currently, the age of patients with spine disease tends to be younger. Adolescent Idiopathic Scoliosis (AIS) has affected 1-3% of children in the United States due to the structural spinal deformity in the coronal plane [1]. Most children with AIS will suffer back pain or behavior limitations in their adulthood [2]. AIS can be categorized two types anatomically: structural scoliosis and functional scoliosis. Treatments of AIS are divided into several parts depending on the increasing Cobb angle, including observation, bracing, surgery, physical therapy, chiropractic treatment, and electrical stimulation. When the deformity angle less than 20°, the treatments involve observation, however, if the angle between 40° and 50°, the managements of these patients are suggested with bracing and surgery [3].

Radiography has been used to get spine data in the clinic for a long time. Recently another measurement in adolescents with idiopathic scoliosis named raster stereography has been widely used. Compared to X-ray imaging, raster stereography is radiation-free, and can present a three-dimensional modeling of spine immediately. Some studies have illustrated that there was still a lack of reliability of raster stereography [4]. However another study stated the Cobb angles calculated by raster stereography were similar to that of X-rays, and the thoracic kyphosis and lumbar scoliosis had a strong correlation with radiographs [5].

The center of pressure (COP) of the foot is the point of location of the vertical ground force vector [6]. Precious research has focused on the center of pressure on normal gait, such as different walking speed, gender, and age periods [7-9], but rarely on disabled gait analysis. COP of the rear foot, mid foot, and fore foot corresponds to the heel strike phase, the mid-stance phase, and the terminal stance phase respectively [10-12]. The foot COP velocities can be calculated during different stance phase. The spatial-temporal characteristics of COP trajectory would be related to the dynamic functional behavior and it also is a way to assess the postural sway [13].

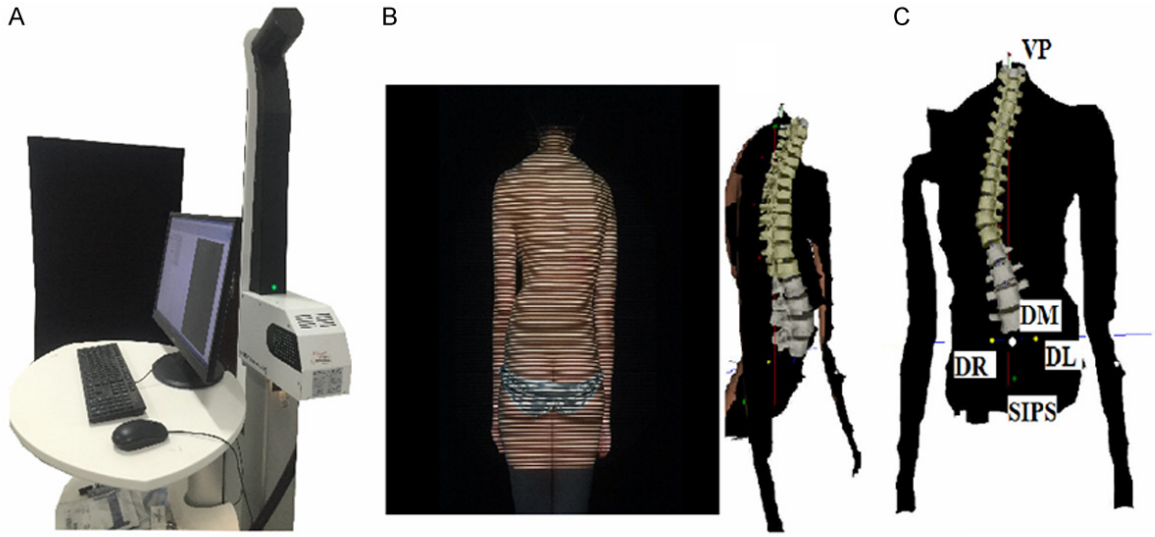

Figure 1. DIERS Formetric system, with the spotlight lining onto the subject's back and the signals are calculated by the computer (A). Visible spine of subject from different directions (B). Axis for coordinate system: VP-SP and DL-DR in the frontal plane, including vertebra prominens (VP), the right lumbar dimple (DR), the left lumbar dimple (DL), the medium lumbar dimple (DM) and the spinae iliaca posterior superior (SIPS) (C).

This study aimed to measure the spatial-temporal gait parameters characteristics of scoliosis subjects (I and II). The hypothesis to be tested was that spine deformation effects gait performance, and that II would present more ankle dorsiflexion and hip abduction, but less hip flexion than I. The second hypothesis was that I may get larger COP velocity than II in mid-stance phase.

Methods

Subjects

Sixteen subjects (age = 17 ± 3.39 years, height = 158.75 ± 10.28 cm, weight = 43.2 ± 8.26 kg) participated in this study. All subjects had no history of upper or lower limb injury. According to the situation of the spine, these subjects were divided into two groups, including observation group (I) and brace group (II). Data of right foot was collected for study analysis.

Materials

Static posture data was obtained by using the DIERS Formetric 4D analysis system (DIERS International GmbH, Schlangenbad, Germany). The DIERS Formetric 4D system can capture 10 picture frames per second for 5 seconds and make these pictures to reconstruct a 3D image of a spine. The kinematics data of ankle and hip was captured by the eight-camera three-dimensional motion analysis system (VICON Motion System Ltd., Oxford, England) with 200 Hz. Sixteen reflective markers (diameter: 14 mm) were placed on the left and right lower limbs according to the standard Plug-in Gait Model [14], including anterior iliac spine, posterior iliac spine, lateral mid-thigh, lateral knee, lateral mid-shank, lateral malleolus, second metatarsal head and calcaneus. Data of center of pressure (COP) was collected by Novel EMED force plate (Novel GmbH, Munich, Germany) with the frequency of 50 Hz. The total gait cycle was divided into three phases based on previous study [15], which are heel strike phase (i), mid-stance phase (ii) and terminal stance phase (iii). The heel strike phase starts from heel first contact to the first metatarsal contact the force plate. The mid-stance phase starts from the first metatarsal contact to all metatarsal contact the force plate and the terminal stance phase starts from the heel off to the toes off the plate.

Experimental procedure

Five reflective makers were stuck on the subject back, including vertebra prominens (VP), the right lumbar dimple (DR), the left lumbar dimple (DL), the medium lumbar dimple (DM)

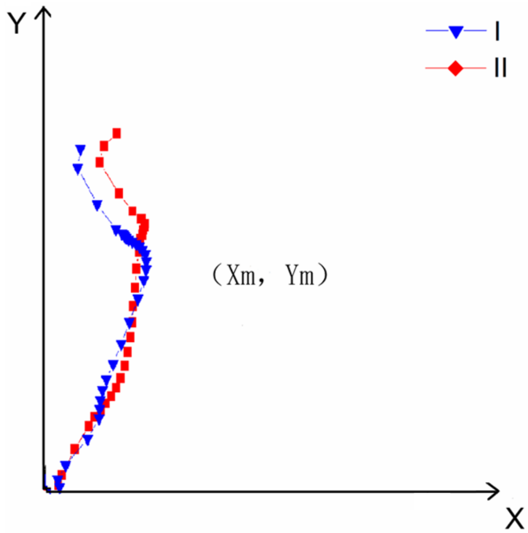

Figure 2. Trajectory of COP during a gait.

and the spinae iliaca posterior superior (SIPS). A digital image was presented in the computer to reconstruct the spine and the scoliosis angle is obtained from this model (**Figure 1**). The subject was required standing in front of the ST scanner at a distance of 2 meters for 5 seconds with barefoot, 3 successful trails for each subject were collected.

After scanning, the kinematics and kinetic data was collected. The gait cycle began when the right heel initially touched the pressure plate and ended when the right heel made contact with the pressure plate again. The hip, ankle ROM, and COP were calculated during the stance phase (SP) of the gait cycle simultaneously. Subjects were required walking with normal speed, they had 5 minutes to warm up and familiar the experiment walking path. Five successful trials were collected for each subject. The COP trajectory was calculated into coordinates X and Y, which were normalized of the feet length and width. COP velocity (v_i) (cm/s) we calculated with following equation [16]:

$$D = \sum_{m}^{n} \sqrt{(X_m - X_{m+1})^2 + (Y_m - Y_{m+1})^2}$$

$v_i = D/t$

From the **Figure 2**, (X_m, Y_m) was the coordinate point of the trajectory of the COP, and (X_{m+1}, Y_{m+1}) was the following point. D was summed from the point *m* to the point *n*, and the frames were recorded to calculate the COP velocity of the heel strike, mid-stance and terminal stance respectively.

Data analysis

The DIERS Formetric 4D and DIERS Pedoscan Systems were used to collect data from the subjects. The range of motion (ROM) of joints was the difference value between maximum and minimum angle. COP trajectory can be calculated by the EMED system, the length differences of i, ii and iii between I and II can be obtained by SPSS 17.0 (SPSS Inc., Chicago, IL, USA). Independent-sample T test was used to calculate the significance of all variables between I and II with statistical differences established at 0.05. Power was calculated by using PASS, and power ≥ 0.8 indicated the data could be trusted.

Ethics approval

This study was approved by the Human Ethics Committee of Ningbo University (ARGH), all methods were abided by the regulations. All subjects were provided the informed content.

Results

The ankle and hip angle

The results from this study provide a good description of the kinematics and kinetics data during the stance phase of gait cycle, especially the peak angle of ankle and hip, the velocity of the COP and the time percentage of different phases. **Figure 2** illustrates the mean angle with standard deviation curve of ankle and hip in sagittal and frontal plane during a gait cycle. From the **Table 1**, II shows greater ankle dorsiflexion (19.41 ± 0.69, 10.12 ± 1.22, $p<0.001$) but less plantar flexion than I (-4.67 ± 1.23, -9.29 ± 1.15, $p<0.001$). Furthermore, II presents less hip flexion than I (25.79 ± 1.36, 29.58 ± 0.99, $p<0.001$) but more hip abduction (-4.04 ± 0.38, 0.14 ± 1.09, $p<0.001$).

The COP velocity

In the **Table 2**, comparing with heel strike phase (12.83 ± 3.23) and terminal stance phase (27.30 ± 4.43), II (21.66 ± 3.18) presented less COP velocity than I (36.46 ± 3.27, p=0.022) during mid-stance and COP velocity of mid-stance phase (31.95 ± 8.84) is the largest.

Table 1. Peak angle values of ankle and hip between I and II (˚)

		I	II	Power
Ankle	Dorsiflexion (*)	10.12 ± 1.22	19.41 ± 0.69	0.98
	Plantarflexion (*)	-9.29 ± 1.15	-4.67 ± 1.23	0.98
	Inversion (*)	4.20 ± 0.35	2.85 ± 0.63	0.95
	Eversion (*)	0.89 ± 0.33	1.49 ± 0.25	0.95
Hip	Flexion (*)	29.58 ± 0.99	25.79 ± 1.36	0.95
	Extension (*)	-7.14 ± 0.89	-10.28 ± 0.45	0.97
	Adduction (*)	7.27 ± 0.96	4.69 ± 0.74	0.96
	Abduction (*)	0.14 ± 1.09	-4.04 ± 0.38	0.95

Note: * indicates a significant difference between I and II, Minus '-'represents position relative defined motion axis.

Table 2. COP velocity of three periods (cm/s)

	I Mean (SD)	II Mean (SD)	p (I-II)
Heel strike	8.94 (1.37)	13.82 (1.07)	0.005*
Mid-stance	36.46 (3.27)	21.66 (3.18)	0.022*
Terminal stance	22.21 (2.78)	26.10 (2.16)	0.04*

Note: * indicates a significant difference.

Table 3. Percentage of three periods in a gait stance phase (%)

	I Mean (SD)	II Mean (SD)	p (I-II)
Heel strike	7.46 (0.01)	7.10 (0.01)	0.75
Mid-stance	38.06 (0.03)	34.71 (0.06)	0.42
Terminal stance	54.47 (0.04)	58.18 (0.04)	0.29

Note: * indicates a significant difference.

The phase percentage of gait

There was no significant difference in the time of three periods of standing phase (**Table 3**).

Discussion

This study investigated the spatial-temporal gait parameters characteristics of scoliosis subjects (I and II), including kinematics data of ankle and hip (**Figure 3**), velocity of COP and percentages of three stance phases. The major finding was that II presented more ankle dorsiflexion and less plantar flexion than I and at the joint of hip, II showed more hip extension, adduction but less flexion and abduction than I. These findings correspond with our first hypothesis. Furthermore, the COP velocity of I was larger than II during the mid-stance phase, which is identical with the second hypothesis.

In this study, there was a significant difference of COP velocity between I and II during the heel strike phase, and II presented larger than I (p=0.005). Some prior studies stated that more ankle dorsiflexion may have benefit on ankle stability [17]. But from the perspective of scoliosis, previous study has showed that dynamic imbalances are increased according to the severity of the Cobb angle, the joints motion may exist differences between left and right foot because of the deformation [18]. Asymmetric gait patterns induce gait instability, resulting in high risk of falls and gait inefficiency; it may have influence on COP velocity [19]. From **Figure 2**, I presented less heel strike time than II, there would be more time to prepare for the flat-foot landing, and it also had less dorsiflexion than II at the end of heel strike phase. Less dorsiflexion angle was interpreted as a tendency for a flat-footed landing [20]. A previous study illustrated that COP controls the forward procession of the body during the gait [21] and showed that the mid-stance phase plays an important role in a gait, almost equivalent to the single stance phase [22]. Therefore, COP velocity of mid-foot stance may have influence on gait speed. During mid-stance phase, the percentage of mid-stance and COP velocity of I was larger than II. The COP velocity of I during mid-stance phase showed larger than heel strike phase and terminal stance phase. But the COP velocity of II during mid-stance phase was less than terminal stance phase. A faster COP velocity indicates a rapid forward weight shift in COP during this phase [23]. It's difficult for II to get a fast forward weight shift compared with I, worse spine condition of II may be one of the risk for this result. Following the terminal stance phase, COP velocity peaks also indicated a weight shift [24]. Ankle plantarflexion with greater inversion of I occurred during this phase. Previous studies have shown that greater ankle plantarflexion combined with ankle inversion were associated with chronic ankle instability [25]. Ankle plantarflexion reducing got a benefit for gait balance [17]. No significant differences existed in time percentage between I and II. At the joint of hip, II exhibited less flexion and greater abduction than I. Limitation in hip flexion is associated with low back pain and physical function [26]. In addition, more hip abduction was also relative to low back pain, which could support that the worse spine deformation and the less COP velocity of II [27].

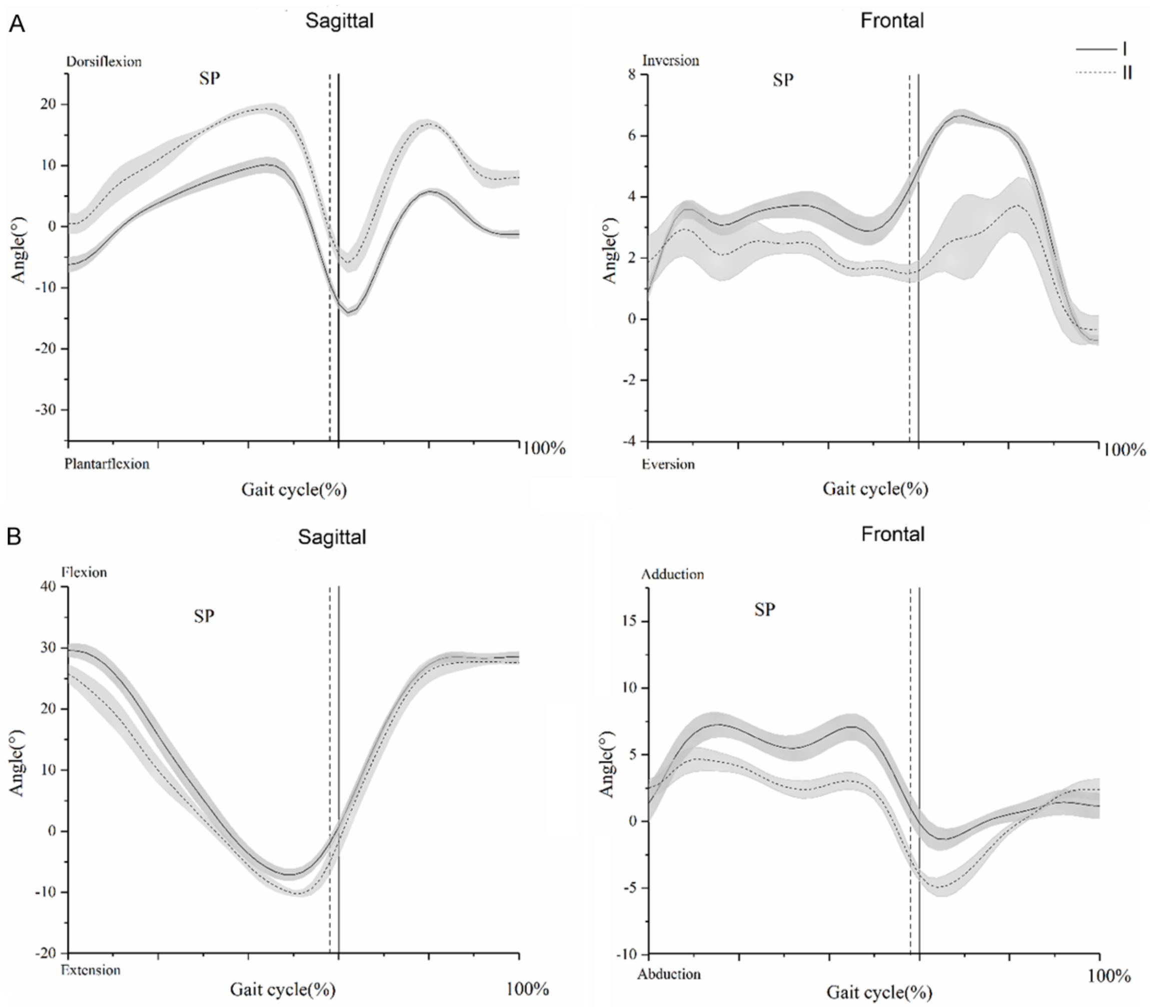

Figure 3. Mean angle with standard deviation curve of ankle (A) and hip (B) during a gait cycle in sagittal and frontal plane (I-solid line, II-dashed line, SP-stance phase).

Compare to I, II showed more hip extension and abduction, reduction of motion could be considered as a compensation mechanism to limit the progression of body imbalance [28].

The present study has several potential limitations. First, the sample size was fairly small, more different types of scoliosis, including surgery, shall be collected in future study. In addition, plantar pressure measurement could be carried out in the next experiment, which is a crucial parameter to analyze the kinetics of gait.

Conclusion

In conclusion, II showed greater ankle dorsiflexion than I and obtained more ankle stability during the heel strike phase. Lack of ankle stability may result in chronic ankle injury and falling. However II presented greater hip abduction, it may be a risk to cause low back pain. Both of them could have effects on COP velocity. Finally, the condition of spine deformation is also a crucial risk of COP velocity.

Acknowledgements

The study was sponsored by the National Natural Science Foundation of China (8130-1600), K.C.Wong Magna Fund at the Ningbo University.

Disclosure of conflict of interest

None.

Address correspondence to: Feng Ren, Faculty of Sports Science, No. 818 Fenghua Road, Ningbo University, Ningbo 315211, China. Tel: +86-574876-09369; E-mail: renfengnb@yeah.net

References

[1] Soucaco PN, Zacharis K, Soultanis K, Gelalis J, Xenakis T and Beris A. Risk factors for idiopathic scoliosis: review of a 6-year prospective study. Orthopedics 2009; 23: 833-838.

[2] Asher MA, Burton DC. Adolescent idiopathic scoliosis: natural history and long term treatment effects. Scoliosis 2006; 1: 1-10.

[3] Chen KC and Chiu EH. Adolescent idiopathic scoliosis treated by spinal manipulation: a case study. J Altern Complement Med 2008; 14: 749.

[4] Schroeder J, Reer R and Braumann KM. Video raster stereography back shape reconstruction: a reliability study for sagittal, frontal, and transversal plane parameters. Eur Spine J 2015; 24: 262-269.

[5] Knott P, Sturm P, Lonner B, Cahill P, Betsch M and Mccarthy R. Multicenter comparison of 3d spinal measurements using surface topography with those from conventional radiography. Spine Deformity 2016; 4: 98-103.

[6] Chesnin KJ, Selby-Silverstein L and Besser MP. Comparison of an in-shoe pressure measurement device to a force plate: concurrent validity of center of pressure measurements. Gait Posture 2000; 12: 128-33.

[7] Fuchioka S, Iwata A, Higuchi Y, Miyake M, Kanda S and Nishiyama T. The forward velocity of the center of pressure in the midfoot is a major predictor of gait speed in older adults. Int J Gerontol 2015; 9: 119-122.

[8] Qiu H and Xiong S. Center-of-pressure based postural sway measures: reliability and ability to distinguish between age, fear of falling and fall history. Inter J Ind Ergonom 2015; 47: 37-44.

[9] Chiu MC, Wu HC and Chang LY. Gait speed and gender effects on center of pressure progression during normal walking. Gait Posture 2013; 37: 43-48.

[10] Schmid M, Beltrami GD and Verni G. Centre of pressure displacements in trans-femoral amputees during gait. Gait Posture 2005; 21: 255-262.

[11] Cornwall MW and Mcpoil TG. Velocity of the center of pressure during walking. J Am Podiatric Med Assoc 2000; 90: 334-338.

[12] Fuchioka S, Iwata A, Higuchi Y, Miyake M, Kanda S and Nishiyama T. The forward velocity of the center of pressure in the midfoot is a major predictor of gait speed in older adults. Int J Gerontol 2015; 9: 119-122.

[13] Baloh RW, Jacobson KM, Beykirch K and Honrubia V. Static and dynamic posturography in patients with vestibular and cerebellar lesions. Arch Neurol 1998; 55: 649.

[14] Iii RBD, Õunpuu S, Tyburski D and Gage JR. A gait analysis data collection and reduction technique. Hum Movement Sci 1991; 10: 575-587.

[15] Chiu MC, Wu HC and Chang LY. Gait speed and gender effects on center of pressure progression during normal walking. Gait Posture 2013; 37: 43-48.

[16] Yan L, Yan C, Luximon A and Zhang M. Effects of heel base size, walking speed, and slope angle on center of pressure trajectory and plantar pressure when wearing high-heeled shoes. Hum Movement Sci 2015; 41: 307-319.

[17] Delahunt E, O'Driscoll J and Moran K. Effects of taping and exercise on ankle joint movement in subjects with chronic ankle instability: a preliminary investigation. Arch Phys Med Rehab 2009; 90: 1418-1422.

[18] Haumont T, Gauchard GC, Lascombes P and Perrin PP. Postural instability in early-stage idiopathic scoliosis in adolescent girls. Spine 2011; 36: 847-54.

[19] Patterson KK, Gage WH, Brooks D, Black SE and Mcilroy WE. Evaluation of gait symmetry after stroke: a comparison of current methods and recommendations for standardization. Gait Posture 2010; 31: 241-246.

[20] Ko SU, Ling SM, Winters J and Ferrucci L. Age-related mechanical work expenditure during normal walking: the baltimore longitudinal study of aging. J Biomech 2009; 42: 1834-1839.

[21] Schmid M, Beltrami GD and Verni G. Centre of pressure displacements in trans-femoral amputees during gait. Gait Posture 2005; 21: 255-262.

[22] Jamshidi N. Differences in center of pressure trajectory between normal and steppage gait. J Res Med Sci 2010; 15: 33-40.

[23] Chiu MC, Wu HC and Chang LY. Gait speed and gender effects on center of pressure progression during normal walking. Gait Posture 2013; 37: 43-48.

[24] De CA, Vanrenterghem J, Willems T, Witvrouw E and De CD. The trajectory of the centre of pressure during barefoot running as a potential measure for foot function. Gait Posture 2008; 27: 669-675.

[25] Chinn L, Dicharry J and Hertel J. Ankle kinematics of individuals with chronic ankle instability while walking and jogging on a treadmill in shoes. Phys Ther Sport 2013; 14: 232-239.

[26] Mellin G. Correlations of hip mobility with degree of back pain and lumbar spinal mobility in chronic low-back pain patients. Spine 1988; 13: 668-70.

[27] Viggiani D and Callaghan JP. A hip abduction exercise prior to prolonged standing increased movement while reducing cocontraction and low back pain perception in those initially reporting low back pain. J Electromyogr Kinesiol 2016; 31: 63-71.

[28] Chen PQ, Wang JL, Tsuang YH, Liao TL, Huang PI and Hang YS. The postural stability control and gait pattern of idiopathic scoliosis adolescents. Clinical Biomech 1998; 13: S52-S58.