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Research Article

A New Potential Indicator in Differentiating Patients with Lumbar Spinal Stenosis and Lumbar Intervertebral Disc Degeneration

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Abstract

Background: Center of pressure (CoP) trajectory is one of the gait parameters that is widely used for clinical assessments. Moreover, the CoP trajectory could be adversely affected by anatomic and mechanical factors that involve foot function, which was shown to be correlated with musculoskeletal diseases. The aim of this study is to compare angle-associated parameters of gait in patients with different lumbar spinal disorders.
Methods: The subjects suffered from the same levels of spine impairment, including patients with lumbar spinal stenosis (LSS) and lumbar intervertebral disc degeneration (LIDD) were recruited in this study. The spatio-temporal angular parameters associated with the CoP of the subjects during their gait were collected and examined. The measurements were used to calculate the CoP angle and symmetry angle (SA). Then the butterfly diagram (BD) intersection angle was introduced as a new potential parameter in gait assessment.
Results: The results of the current study showed that CoPs and SAs did not vary between the two groups ($P > 0.05$). The BD intersection angle, however, indicated some variations between patients with LSS and LIDD ($P < 0.05$).
Conclusion: While the results showed that CoP angles and SAs did not differ between the LSS and LIDD groups, it is hypothesized that such disorders that affect the gait could be reflected in the BD intersection angle. Therefore, the BD intersection angle is suggested as a clinical indicator in clarifying patients with lumbar spinal disorders.

Keywords: Kinetics; Gait; Spinal Stenosis; Intervertebral Disc Degeneration

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Background

Motor patterns reflect biomechanical characteristics and sensory activities (1). Gait adaptations could be induced by injuries so that the resulted compensations lead to less pain while moving (2). Pathological gaits have been widely studied and characterized through introducing a variety of gait parameters (3). Normally, aging is accompanied by degenerative changes and spinal narrowing which could be exacerbated due to various factors (4).

Lumbar spinal stenosis (LSS) is considered as the most common degenerative change in the course of aging (5, 6). The economic burden of such spinal diseases is notable (7-9). LSS compromises neural functionality and causes significant debilitation. The most and the least commonly involved levels are the L4-L5 and the L5-S1, respectively (4). Lumbar intervertebral disc degeneration (LIDD) could also end in LSS. The similarity of symptoms barricades the differentiation between LSS and LIDD (4, 6). Although screening patients' behaviors due to pain, along with neuroimaging and electromyography data could be valuable in the differential diagnosis (4), clear radiological demonstration of LSS has been proved to play a key role (10). Imaging modalities, however, could not accurately reveal the spinal canal narrowing in all individuals (11). Therefore, there is a paucity in studies accounting for quantitative comparison between spinal disorders that affect the same anatomical regions. In the present work, we considered two groups of patients with the same levels of lumbar spinal involvement.

According to Chang et al. (12), CoP angle, also known as toe-out angle, is shown to be related to the clinical issues which are evident radiologically (13, 14). The CoP trajectory could be adversely affected/compensated by anatomical and mechanical factors that involve foot function (15, 16).

The CoP angle has been shown to be correlated with musculoskeletal diseases (12). Since prominent asymmetries in gait parameters could possibly indicate pathological states and consequent compensations (17-19), the symmetry angle (SA) of the CoP trajectory progression has been surveyed in the literature (20).

In addition to the CoP angles and the corresponding symmetry, parameters of butterfly diagram (BD) are capable of evaluating gait compensations with aging or in different pathological states (12, 21, 22). BD addresses continuous trajectory of the CoP in the transverse plane generated by the plantar pressure distribution during the gait cycle. The related parameters could be used to assess certain impairments in patients with musculoskeletal disorders (MSDs) (13, 23).

We investigated the three CoP angle-associated parameters, i.e., the CoP angle, the CoP SA, and the BD intersection angle among patients with LSS and LIDD.

Methods

To compare CoP, SAs, and BD intersection angles in the two groups of patients with lumbar spinal disorders, a total of 16 subjects with either LSS or LIDD were recruited. A Physical Medicine and Rehabilitation (PM&R) specialist diagnosed their condition based on spinal magnetic resonance images (MRIs). The study exclusion criteria included a previous history of fractures or surgery in either the spine or the lower extremities. Additionally, those with cardiovascular, respiratory, or cerebral conditions were excluded. All subjects were free from known progressive neurodegenerative diseases and ambulatory problems. All subjects suffered from L4-L5 or L5-S1 involvement of lumbar spine levels. Patients with LIDD were mostly affected by dehydration, bulging, and protrusion of the intervertebral disc. In patients with LSS, the condition was manifested by the anatomical narrowing of the spinal canal. All patients signed a written informed consent form.

The subjects were individually instructed to carry out the walking test. They were asked to walk normally on a level plantar pressure distribution measurement system (Gait analysis FDM-T, Zebris Medical GmbH, Germany). The significant difference revealed in this study took advantage of statistical and experimental requirements regarding step numbers in each trial (24). Three successful trials of each individual were recorded and analyzed. The CoP and BD intersection angles were obtained by implementing image processing methods. SAs were determined using the collected parameters directly. To compare the angles between the LIDD and LSS groups, t-test analyses were performed, with the level of significance set at 0.05.

To evaluate the CoP angle, the CoP progression of all the recorded steps of the three trials were considered separately for the left and right feet. Angle sign definition is depicted in figure 1. θ_L and θ_R denote the left and right foot CoP angles, respectively. The positive sign was attributed to external rotation and the negative sign to the internal rotation compared to the neutral line (NL).

The CoP angle was defined as the angle between the line connecting the initial point to the end point of the CoP position and the virtual line of progression during gait (Figure 1).

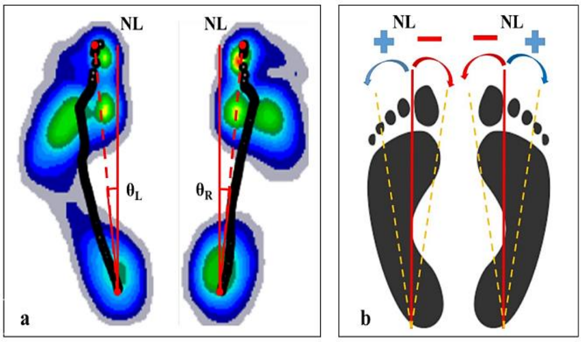
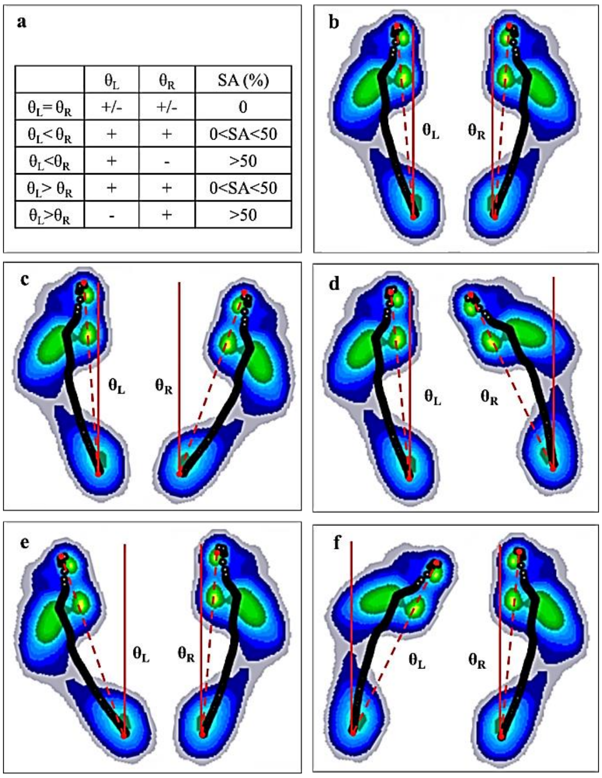


Figure 1. Center of pressure (CoP) angles: (a) Angle definition; (b) Definition of the angle sign with respect to the neutral line (NL) indicated by a solid line

Equation (1) provides a measure of the percentage of difference between the left and right side that quantifies the asymmetry of the CoP angle (25):

$$SA\ (\%) = \frac{(45^{\circ} - \arctan(\theta_{left}/\theta_{right}))}{90^{\circ}} \times 100 \qquad (1)$$

Where SA is the symmetry angle and varies between 0 and 100% that refers to fully symmetric and fully asymmetric conditions, respectively (Figure 2). $\theta_{left}/\theta_{right}$ corresponds to left-/right-side parameters of interest (they could be considered as CoP angles that will be discussed in more details later).



	θ_L	θ_R	SA (%)
$\theta_L = \theta_R$	+/-	+/-	0
$\theta_L < \theta_R$	+	+	0<SA<50
$\theta_L < \theta_R$	+	-	>50
$\theta_L > \theta_R$	+	+	0<SA<50
$\theta_L > \theta_R$	-	+	>50

Figure 2. Different conditions that symmetry angle (SA) can accept based on deviation of footprint during double-support phase of walking.

The CoP lines of the BD form two included congruent angles or BD intersection angles (θ_B) at the middle vertex of the crossing angles. These angles are shown in figure 3.

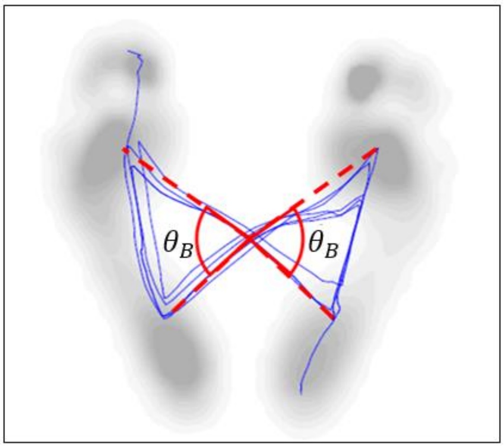


Figure 3. Butterfly diagram (BD) intersection angles (θ_B) represented by center of pressure (CoP) trajectory of both feet

Results

In this study, the CoP trajectory of subjects with either LSS or LIDD during walking was explored. The mean age, height, weight, and body mass index (BMI) of the subjects were 50.53 ± 9.13 years old, 162.8 ± 8.3 cm, 76.8 ± 10.2 kg, and 29.7 ± 3.6 kg/m^2, respectively.

The results showed that the CoP angles and SAs did not differ between the patients with LSS and patients with LIDD ($P > 0.05$). Estimated values for SAs indicated asymmetry between the left and right lower limb of both groups (Table 1). The percentage of difference of SA in patients with LIDD was lower than that of the LSS group.

Table 1. Center of pressure (CoP)-associated angles

	LIDD (mean ± SD)	LSS (mean ± SD)	P-value
θ_R (deg.)	5.66 ± 3.65	8.59 ± 6.39	0.12
θ_L (deg.)	2.56 ± 4.65	3.59 ± 4.89	0.36
θ_B (deg.)	79.96 ± 11.26	60.67 ± 24.36	< 0.01*
SA (%)	29.98 ± 26.64	36.38 ± 20.28	0.33

LIDD: Lumbar intervertebral disc degeneration; LSS: Lumbar spinal stenosis
*The asterisk indicates significance at P < 0.05.

The results mentioned in table 1 pointed out that the CoP angles of both left and right feet could not differentiate between the patients with LSS and patients with LIDD (P > 0.05). Moreover, there was no significant difference in the SA between the two groups. Among the three CoP-associated angles, only the BD intersection angles differed between the two groups (P < 0.05).

Discussion

The quantitative differentiation of LSS from those medical conditions that mimic LSS manifestations could be clinically important (4). There are two reasons for this issue. First, verifying LSS in all patients based on radiological imaging and common clinical criteria face certain ambiguities (11). Secondly, exacerbation of the intervertebral disc degeneration might confine aged people ambulation and sensation when it leads to stenosis. These patients are also more prone to concomitant medical illnesses that correspond with surgical operations (5). Therefore, introducing an indicator that is capable of comparative differentiation could be useful in clinical settings.

It can be concluded that the nature of θ_B which involves not only the left- and right-side of the body functions, but also the interplay between them, accounts for a more general state compared to the SA. The introduction of BD intersection angles, as a quantitative and comparative assessment of gait compensation, in lumbar spinal conditions is of clinical value remembering related prevalence and incidence. While LSS is considered to be a highly frequent medical condition in orthopedic and neurosurgical practice (5), LIDD could also develop/exacerbate to LSS, mimicking similar symptoms (4, 6). In this study, we comparatively investigated BD intersection angles of the two groups of subjects. Based on these findings, compensations that LSS and LIDD disorders enforce on gait could be reflected in BD intersection angles (P < 0.05).

The limitations of the present work included low sample sizes, and lack of clinical assessments e.g. pain score, severity of the stenosis, and functionality of patients. Such clinical assessments could correlate the patient's medical condition to spatio-temporal gait parameters (26). Future works will consider gender-specific and age-specific populations to provide a better understanding of any existing correlation between the patients with LSS and patients with LIDD.

Conclusion

The aim of this study was to assess and compare angle-associated parameters of gait kinematics between two groups of patients with anatomical lumbar impairments. In this investigation, subjects with the same level of spinal problems, one with LSS and the other with LIDD were considered. The parameters of interest were extracted from CoP positioning of the subjects with LSS and LIDD during their gait cycles. We also introduced BD intersection angles. Comparing kinetics of patients with the same lumbar spinal zone problem have not been yet studied except in an ongoing work by the authors. The CoP and SA angles did not differ between the two groups (P > 0.05), while BD intersection angles showed significant differences. The results could be noted in clinical assessment of the aforementioned spinal problems. It could be inferred that BD intersection angles of gait could be a bio-index to differentiate between individuals with LSS and LIDD.

Conflict of Interest

The authors declare no conflict of interest in this study.

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References

1. Grasso R, Bianchi L, Lacquaniti F. Motor patterns for human gait: Backward versus forward locomotion. *J Neurophysiol*. 1998;80(4):1868-85. doi: 10.1152/jn.1998.80.4.1868. [PubMed: 9772246].
2. Cully A, Clune J, Tarapore D, Mouret JB. Robots that can adapt like animals. *Nature*. 2015;521(7553):503-7. doi: 10.1038/nature14422. [PubMed: 26017452].
3. Carriero A, Zavatsky A, Stebbins J, Theologis T, Shefelbine SJ. Determination of gait patterns in children with spastic diplegic cerebral palsy using principal components. *Gait Posture*. 2009;29(1):71-5. doi: 10.1016/j.gaitpost.2008.06.011. [PubMed: 18676146].
4. Wencel J, Olson KA. Lumbar spinal stenosis: A literature review. *J Manual Manipulative Ther*. 1999;7(3):141-8. doi: 10.1179/106698199790811663.
5. Clinchot DM, Kaplan PE, Lamb JF. Lumbar spinal stenosis in an elderly patient. *J Gerontol A Biol Sci Med Sci*. 1998;53(1):M72-M75. doi: 10.1093/gerona/53a.1.m72. [PubMed: 9467437].
6. Deyo RA, Mirza SK, Martin BI, Kreuter W, Goodman DC, Jarvik JG. Trends, major medical complications, and charges associated with surgery for lumbar spinal stenosis in older adults. *JAMA*. 2010;303(13):1259-65. doi: 10.1001/jama.2010.338. [PubMed: 20371784]. [PubMed Central: PMC2885954].
7. Genevay S, Courvoisier DS, Konstantinou K, Kovacs FM, Marty M, Rainville J, et al. Clinical classification criteria for neurogenic claudication caused by lumbar spinal stenosis. The N-CLASS criteria. *Spine J*. 2018;18(6):941-7. doi: 10.1016/j.spinee.2017.10.003. [PubMed: 29031994].
8. Machado GC, Maher CG, Ferreira PH, Harris IA, Deyo RA, McKay D, et al. Trends, complications, and costs for hospital admission and surgery for lumbar spinal stenosis. *Spine (Phila Pa 1976)*. 2017;42(22):1737-43. doi: 10.1097/BRS.0000000000002207. [PubMed: 28441309].
9. Iatridis JC, Kang J, Kandel R, Risbud MV. New horizons in spine research: Intervertebral disc repair and regeneration. *J Orthop Res*. 2017;35(1):5-7. doi: 10.1002/jor.23499. [PubMed: 28114734]. [PubMed Central: PMC5482231].
10. Jonsson B, Annertz M, Sjoberg C, Stromqvist B. A prospective and consecutive study of surgically treated lumbar spinal stenosis. Part II: Five-year follow-up by an independent observer. *Spine (Phila Pa 1976)*. 1997;22(24):2938-44. doi:

10.1097/00007632-199712150-00017. [PubMed: 9431630].
11. Steurer J, Roner S, Gnannt R, Hodler J. Quantitative radiologic criteria for the diagnosis of lumbar spinal stenosis: A systematic literature review. *BMC Musculoskelet Disord*. 2011;12:175. doi: 10.1186/1471-2474-12-175. [PubMed: 21798008]. [PubMed Central: PMC3161920].
12. Chang A, Hurwitz D, Dunlop D, Song J, Cahue S, Hayes K, et al. The relationship between toe-out angle during gait and progression of medial tibiofemoral osteoarthritis. *Ann Rheum Dis*. 2007;66(10):1271-5. doi: 10.1136/ard.2006.062927. [PubMed: 17267516]. [PubMed Central: PMC1994298].
13. Kalron A, Frid L. The "butterfly diagram": A gait marker for neurological and cerebellar impairment in people with multiple sclerosis. *J Neurol Sci*. 2015;358(1-2):92-100. doi: 10.1016/j.jns.2015.08.028. [PubMed: 26318202].
14. Prosperini L, Fortuna D, Gianni C, Leonardi L, Pozzilli C. The diagnostic accuracy of static posturography in predicting accidental falls in people with multiple sclerosis. *Neurorehabil Neural Repair*. 2013;27(1):45-52. doi: 10.1177/1545968312445638. [PubMed: 22593115].
15. Fuller EA. Center of pressure and its theoretical relationship to foot pathology. *J Am Podiatr Med Assoc*. 1999;89(6):278-91. doi: 10.7547/87507315-89-6-278. [PubMed: 10384754].
16. De Cock A., Vanrenterghem J, Willems T, Witvrouw E, De Clercq D. The trajectory of the centre of pressure during barefoot running as a potential measure for foot function. *Gait Posture*. 2008;27(4):669-75. doi: 10.1016/j.gaitpost.2007.08.013. [PubMed: 17997096].
17. Sadeghi H, Allard P, Prince F, Labelle H. Symmetry and limb dominance in able-bodied gait: A review. *Gait Posture*. 2000;12(1):34-45. doi: 10.1016/s0966-6362(00)00070-9. [PubMed: 10996295].
18. Gouwanda D, Senanayake SM. Identifying gait asymmetry using gyroscopes-a cross-correlation and Normalized Symmetry Index approach. *J Biomech*. 2011;44(5):972-8. doi: 10.1016/j.jbiomech.2010.12.013. [PubMed: 21306714].
19. Winter DA, Sienko SE. Biomechanics of below-knee amputee gait. *J Biomech*. 1988;21(5):361-7. doi: 10.1016/0021-9290(88)90142-x. [PubMed: 3417688].
20. Mawase F, Haizler T, Bar-Haim S, Karniel A. Kinetic adaptation during locomotion on a split-belt treadmill. *J Neurophysiol*. 2013;109(8):2216-27. doi: 10.1152/jn.00938.2012. [PubMed: 23365187].
21. Kalron A, Dvir Z, Frid L, Achiron A. Quantifying gait impairment using an instrumented treadmill in people with multiple sclerosis. *ISRN Neurol*. 2013;2013:867575. doi: 10.1155/2013/867575. [PubMed: 23878746]. [PubMed Central: PMC3708434].
22. Khanmohammadi R, Talebian S, Hadian MR, Olyaei G, Bagheri H. The relative and absolute reliability of center of pressure trajectory during gait initiation in older adults. *Gait Posture*. 2017;52:194-201. doi: 10.1016/j.gaitpost.2016.11.042. [PubMed: 27915224].
23. Kalron A, Achiron A. The relationship between fear of falling to spatiotemporal gait parameters measured by an instrumented treadmill in people with multiple sclerosis. *Gait Posture*. 2014;39(2):739-44. doi: 10.1016/j.gaitpost.2013.10.012. [PubMed: 24200869].
24. Riva F, Bisi MC, Stagni R. Gait variability and stability measures: Minimum number of strides and within-session reliability. *Comput Biol Med*. 2014;50:9-13. doi: 10.1016/j.compbiomed.2014.04.001. [PubMed: 24792493].
25. Zifchock RA, Davis I, Higginson J, Royer T. The symmetry angle: A novel, robust method of quantifying asymmetry. *Gait Posture*. 2008;27(4):622-7. doi: 10.1016/j.gaitpost.2007.08.006. [PubMed: 17913499].
26. Huang RC, Tropiano P, Marnay T, Girardi FP, Lim MR, Cammisa FP Jr. Range of motion and adjacent level degeneration after lumbar total disc replacement. *Spine J*. 2006;6(3):242-7. doi: 10.1016/j.spinee.2005.04.013. [PubMed: 16651217].