Title

Correlation between spinal and pelvic movements during gait and aggravation of low back pain by gait loading in lumbar spinal stenosis patients

Authors

Wataru Kuwahara[a], Hiroshi Kurumadani[b], Nobuhiro Tanaka[c], Kazuyoshi Nakanishi[c], Haruka Nakamura[d], Yosuke Ishii[a], Akio Ueda[a], Masataka Deie[e], Nobuo Adachi[c], Toru Sunagawa[b]

Affiliations

[a] Health Sciences Major, Graduate School of Biomedical and Health Sciences, Hiroshima University, 1-2-3 Kasumi, Minami-ku, Hiroshima 734-8551, Japan

[b] Laboratory of Analysis and Control of Upper Extremity Function, Graduate School of Biomedical and Health Sciences, Hiroshima University, 1-2-3 Kasumi, Minami-ku, Hiroshima 734-8551, Japan

[c] Department of Orthopaedic Surgery, Graduate School of Biomedical and Health Sciences, Hiroshima University, 1-2-3 Kasumi, Minami-ku, Hiroshima 734-8551, Japan

[d] Department of Rehabilitation, Kibinomori Rehabilitation Hospital, 1-30-1, Kibinomori-Minami, Oamishirasato-shi, Chiba 299-3241, Japan

[e] Department of Orthopaedic Surgery, Aichi Medical University, 1-1 Yazakokarimata, Nagakute-shi, Aichi 480-1195, Japan

Corresponding author

Wataru Kuwahara

Health Sciences Major, Graduate School of Biomedical and Health Sciences, Hiroshima University, 1-2-3 Kasumi, Minami-ku, Hiroshima 734-8551, Japan

E-mail address: wkuwahara1228@gmail.com

Tel.: +81-082-257-5457

Fax: +81-082-257-5457

Word counts

Abstract: 272ords

Main text: 3089 words

Abstract

Background

Lumbar alignment of posterior or anterior tilts affects the exacerbation and remission of symptoms of lumbar spinal stenosis patients. This study aimed to clarify the correlation between spinal and pelvic movements during gait and the aggravation of low back pain after gait loading in lumbar spinal stenosis patients.

Methods

A total of 29 patients with lumbar spinal stenosis completed leg and low back pain assessments and gait analysis before and after gait loading tests. Patients were divided into leg and low back pain change (n = 8), leg pain only change (n = 12), and non-change (n = 9) groups based on the differences of leg and low back pain between before and after the tests. Peak kinematic values of the anterior tilts of the trunk, thoracic spine, lumbar spine and pelvis during the stance phase were obtained via three-dimensional gait analysis.

Results

In the leg and low back pain change group, the anterior lumbar and pelvic tilts were larger after than before the tests; however, in the leg pain only change and non-change groups, only the anterior lumbar tilt was larger after than before the tests. Anterior

lumbar tilt before and after the tests negatively correlated with the aggravation of low back pain, and increasing in the anterior pelvic tilt positively correlated with the aggravation of low back pain.

Conclusions

In lumbar spinal stenosis patients, smaller anterior lumbar tilt and larger anterior pelvic tilt during gait loading may affect the aggravation of low back pain by gait loading. Increasing in lumbar lordosis during gait might be one of the factors leading to low back pain in lumbar spinal stenosis patients.

1. Introduction

Lumbar spinal stenosis (LSS) patients frequently complain of numbness and pain in the lower limbs, and neurogenic intermittent claudication [1, 2]. It is known that the lumbar alignment of the posterior or anterior tilts affects exacerbation and remission of symptoms of LSS patients. A previous study [3] showed that in the standing position, the epidural pressure was increased by maximum lumbar extension, but decreased by a 30° forward flexion compared to the upright position in LSS patients.

There are a few studies on trunk tilt before and after a gait loading test for LSS patients. While Suda et al. and Nagai et al. [4, 5] showed an increase in anterior trunk tilt, another study [6] did not show any change after gait loading test. Thus, no consensus has been reached as to spinal and pelvic movements before and after gait loading in LSS patients. We postulated that the differences in results of each study were due to investigating the movement of the whole spine being considered in the previous studies. The thoracic and lumbar movements should be investigated separately to better understand the spinal kinematics of LSS patients during gait before and after gait loading.

Furthermore, 67.6% of LSS patients have low back pain (LBP) [7], and a previous study [8] showed that LBP for LSS patients was improved after decompression surgery without fusion. In this literature, authors discussed that the factors leading to LBP in LSS were the facet joints, ischemia of the nerve roots, and postures of increased lumbar anterior tilt. Considering these facts, there is a possibility that spinal and pelvic movements affect LBP, that are exacerbated by walking.

The purposes of this study were: (1) To investigate both thoracic and lumbar movements during gait in LSS patients before and after gait loading, and (2) To clarify that the aggravation of LBP after gait loading is affected by spinal and pelvic movements during gait in LSS patients. We hypothesized that the anterior lumbar tilt during gait would be increased after gait loading to avoid the appearance of neurogenic intermittent claudication and that the larger anterior lumbar tilt after gait loading would induce LBP in LSS patients.

2. Materials and methods

2.1 Participants

This study included the LSS patients who underwent decompression surgery without fusion at our institute between January 2015 and August 2017. LSS patients were diagnosed based on a review of the patient history, physical examination, and confirmation of LSS by magnetic resonance imaging. All patients had experienced lower-extremity pain and/or numbness and neurogenic intermittent claudication. Patients were excluded if they had significant instability or scoliosis of the lumbar spine, previous spinal surgery, bone tumour, apparent vertebral fracture on plane X-ray, severe hip and/or knee osteoarthritis, inability to walk independently, no increase in leg pain by gait loading. A total of 29 patients with LSS (17 male and 12 female adults) were recruited in the study. In 10 patients who were evaluated by standing lateral radiographs of the whole spine and pelvis [9], the average sagittal vertical axis, thoracic kyphosis, lumbar lordosis, pelvic tilt, sacral slope, and pelvic incidence were 55.4 ± 27.0 mm, 33.4 ± 13.9°, 30.4 ± 17.6°, 33.4 ± 13.9°, 30.2 ± 11.0°, 29.2 ± 14.2°, and 59.4 ± 20.2°, respectively.

This study was approved by the Epidemiology Research Ethical Review Board of our institution (approval number: E Epd-1050-2). All patients received information about the purpose and design of the study, and each of them was provided a written informed consent.

2.2. Protocol (Fig. 1)

All patients performed the following measurements in the week prior to decompression surgery. Initially, they were screened for health status related to LSS by using the MOS 36-item Short-Form Health Survey (SF-36). The SF-36, which consisted of eight subcategories, was used to evaluate health-related quality of life, and a higher score indicated a better health status [10, 11]. The Oswestry Disability Index (ODI) was used to evaluate activities of daily living related to LBP, and a lower score indicated a better health status [12, 13].

Next, patients performed a modified 6-minutes gait loading test with the aim to induce symptoms [14, 15]. They were instructed to walk back and forth along a 10-m walkway as fast as possible for 6-minutes following the instructions "walk as fast as you comfortably can, bearing in mind that you will be walking for six minutes." Patients were allowed to stop and rest during the test as long as they stood. Then, we measured leg pain (LP), LBP, and gait kinematics immediately before (pre-effort) and after (post-effort) the gait loading test. We measured LP and LBP pre-effort after sufficient rest. A walking distance was recorded after the test.

2.3. Assessment of pain intensity before and after gait loading test and classification into groups

We measured patients' LP and LBP intensity using a 100 mm-Visual Analogue Scale (VAS) pre- and post-effort. Patients marked their pain intensity on the 100 mm-

VAS, where 0 mm signified “no pain” and 100 mm signified “the worst pain imaginable.”

ΔLP and ΔLBP were calculated by subtracting the pre-effort VAS scores from post-effort. Patients with ΔLP of ≤0 mm were defined as the non-change group. Furthermore, in patients with ΔLP of >0 mm, because a minimum clinically important change is defined as a change in pain of ≥18 mm on VAS [16], we set the threshold as 18 mm to classify the following groups: LP and LBP change (ΔLBP of ≥18 mm) and LP only change (ΔLBP of <18 mm).

2.4. Gait analysis

A three-dimensional motion analysis system (VICON MX: Vicon Motion Systems, Oxford, UK) with 16 infrared cameras (sampling at 100 Hz) and eight force plates (sampling at 1000 Hz; AMTI, Watertown, USA) recorded LSS patients’ gait. Thirty-five passive reflective markers (14 mm diameter) were attached according to a commercially available kinematic model (Plug-in-gait, Vicon® Peak, Oxford, UK). To examine both thoracic and lumbar motion during gait, eight markers were attached to the spinous processes of C7, T1, T12, and L1 and on both sides of the spinous processes of T1 and L1 [17, 18]. Before gait protocols were started, the static standing reference position of the patients was measured twice. The patients were directed to look straight ahead and keep standing for 5 s. Patients then walked barefoot at a self-selected speed along a 10-m walkway, three times at each pre- and post-effort.

Acquired data was filtered by a 4th-order Butterworth low-pass filter with cut-off frequency of 6 Hz (ButterPlug; Vaquita Software, Zaragoza, Spain). Spatiotemporal parameters: gait velocity, cadence, and stride length, were extracted from the biomechanical model output, and the stride length was normalized to the body height. Using the Vicon Bodybuilder processing software (Vicon Motion Systems), anatomical reference segments: the T1, L1, and pelvic segments, were defined according to a previous study (Fig. 2) [18]. The trunk, thoracic, and lumbar tilts were defined as movements of the T1 segment to the pelvic segment, the T1 segment to the L1 segment, and the L1 segment to the pelvic segment, respectively. Pelvic tilt was defined as the movement of the pelvic segment to the global segment. The positive and negative kinematic data were represented as the anterior and posterior tilt, respectively.

The gait kinematics of the spine and pelvis were expressed relative to the patient’s standing reference position by subtracting the standing reference values from those measured during the gait tasks [19]. Initial contact was identified by the force plates detecting >10 N, while toe-off was defined as the detection of <10 N. Kinematic data included the peak values of each data point during the stance phase both pre- and post-effort. Further, Δ values of all spatiotemporal and kinematic parameters were calculated by subtracting the values at pre-effort from post-effort. The mean values of three trials were used in the statistical analysis. Gait analysis was conducted by one examiner (W.K). To evaluate the intra-rater reliability of kinematic data, 10 healthy male volunteers (mean age: 25 ± 3 years, body height: 1.72 ± 0.05 m, body weight: 63.5 ± 5.1 kg, body mass index (BMI): 21.4 ± 1.0 kg/m^2) underwent gait analysis in two sessions.

2.5. Statistical analysis

Statistical analysis was performed using SPSS for Windows (version 23.0; IBM Japan, Tokyo, Japan). Agreement between measurements was analysed using the intraclass correlation coefficients (ICCs). For this calculation, the one-way random effects model was selected. Furthermore, the standard error of measurement (SEM) was used to estimate absolute repeatability and provide information to delineate intra-individual variability over repeated measurements [20].

A Shapiro-Wilk test was used to analyse normality of data distribution. Next, one-way analysis of variance, Kruskal-Wallis test, and chi-square test were used to assess differences among the three groups (LP and LBP change, LP only change, and non-change). A post hoc analysis was performed using the Tukey-Kramer test or Steel-Dwass test to determine differences among the groups. Differences in spatiotemporal and kinematic data among the groups before and after the gait loading test were examined using a two-way mixed repeated-measure analysis with factors of the groups (LP and LBP change, LP only change, and non-change) and the time effect (pre- and post-effort). If there were significant interactions, simple main effects were evaluated using a Bonferroni test. Correlations between gait velocity and kinematics of the spine or pelvis during gait and ΔLP or ΔLBP were analysed using the Spearman rank correlation coefficient for patients with LSS except for the non-change group. The level of statistical significance was <5%.

3. Results

ICC values for the peak tilts during the stance phase in the trunk, thoracic spine, lumbar spine, and pelvis were 0.635, 0.742, 0.838, and 0.944, respectively. SEM values for the peak tilts during the stance phase in the trunk, thoracic spine, lumbar spine, and pelvis were 3.0°, 2.9°, 1.8°, and 1.4°, respectively.

Based on VAS scores of LP and LBP, 8 patients were included in the LP and LBP change group, 12 in the LP only change group, and 9 in the non-change group. No significant differences were observed in age, height, weight, BMI, sex, walking distance of gait loading test, SF-36 scores, and ODI scores between the groups (Table 1).

No significant differences in VAS scores of LP and LBP pre-effort were observed among the groups (Table 1). The VAS score of LP was significantly higher in the LP and LBP change and LP only change groups than in the non-change group post-effort. The VAS score of LBP was significantly higher in the LP and LBP change group than in the LP only change and non-change groups post-effort.

Gait velocity, cadence, and stride length were significantly higher post-effort than pre-effort in the three groups (Table 2). There were no significant differences in gait velocity, cadence, and stride length between the groups.

There was no significant effect of group, time and interactions on peak anterior trunk and thoracic tilts during the stance phase (Table 2, Fig. 3). Peak anterior lumbar tilt was significantly larger in post-effort than in pre-effort in the three groups, but no significant effect was observed on the anterior lumbar tilt in all groups. Peak anterior pelvic tilt was significantly larger in post-effort than in pre-effort in the LP and LBP change group only.

ΔLP and ΔLBP were significantly higher in the LP and LBP change and LP only change groups than in the non-change group (Table 3). Moreover, ΔLBP was significantly higher in the LP and LBP change group than in the LP only change group. ΔPelvis was significantly higher in the LP and LBP change group than in the LP only change and non-change groups. No significant differences in the other Δ values were observed between the groups.

In patients with LSS except for the non-change group, the peak anterior trunk tilt during the stance phase pre-effort was negatively correlated with ΔLP (Table 4). On the contrary, no significant correlations were observed between gait velocity or other kinematic values and ΔLP. Peak anterior lumbar tilt during the stance phase both pre- and post-effort negatively correlated with ΔLBP, while ΔPelvis positively correlated with ΔLBP (Table 4). In contrast, no significant correlations were observed between gait velocity or other kinematic values and ΔLBP.

4. Discussion

To the best of our knowledge, this is the first study to investigate the thoracic, lumbar, and pelvic movements during gait before and after gait loading in LSS patients, particularly focusing on LBP. Our study provides two important findings. Firstly, anterior tilts of the trunk and thoracic spine showed no change between before and after gait loading; however, lumbar anterior tilt increased after gait loading even in patients with LSS who had no aggravation of LP by gait loading. Secondly, in LSS patients, a smaller anterior lumbar tilt both before and after gait loading and a larger anterior pelvic tilt post-effort compared to pre-effort affected aggravation of LBP by gait loading.

There was no consensus about trunk tilt before and after gait loading because the spinal movements analysed in each study were different [4-6]. As hypothesised, our results showed an increase in the anterior lumbar tilt even in patients with LSS who had no worsened LP after gait loading. In addition, no significant differences were observed between pre- and post-effort in terms of the trunk or thoracic tilts during gait. These findings suggest that LSS might induce the abnormal lumbar movement during gait. In the larger anterior lumbar tilt, the spinal canal becomes larger; thus, the compression of the nerve roots is reduced [3, 21]. Therefore, when performing gait loading test for LSS patients, focusing on the lumbar movement would be important to evaluate the spinal kinematics during gait.

Based on the amount of change in the VAS score of LBP, we classified patients into two groups: the LP and LBP change and LP only change. Interestingly, LBP post-effort and ΔLBP were higher in the LP and LBP change group; however, there was no significant difference between the two groups in LBP pre-effort and other clinical outcomes such as LP, walking distance of gait loading test, SF-36, and ODI. In other words, no difference in intermittent claudication was observed between the LP and LBP change and LP only change groups. Therefore, for patients in the LP and LBP change group, gait loading specifically induced LBP.

The most important result in the present study was that the anterior pelvic tilt in the LP and LBP change group increased post-effort compared to pre-effort. Furthermore, a smaller anterior lumbar tilt during gait, both in the pre- and post-efforts, and a larger increase of the anterior pelvic tilt post-effort compared to pre-effort significantly correlated with higher ΔLBP in patients with LSS except for the non-change group. Kang et al. [22] reported that anterior pelvic tilt in LSS patients was decreased after gait loading. Similar to this, although no significant difference was observed, patients in the LP only change and non-change groups had slightly decreased in the anterior pelvic tilt (mean ΔPelvis was -0.6° and -0.3°, respectively). Thus, an increase in the anterior pelvic tilt in the LP and LBP change group (mean ΔPelvis was 1.4°) was very characteristic. Increasing the anterior pelvic tilt in the standing position increases lumbar lordosis [23]. The smaller anterior lumbar tilt and the increase in the anterior pelvic tilt might cause an increase in lumbar lordosis. Jones et al. [8] reported that the factors leading to LBP in LSS were the facet joints, ischemia of the nerve roots, and postures of increased lumbar anterior tilt. Because excessive lumbar lordosis causes an increase in compressive force within the facet joints [24], the aggravation of LBP by gait loading in patients with LSS might be derived from the facet joints.

In the present study, pelvic range of motion during gait pre-effort was 2.6 ± 0.7° in the LP and LBP change group, 2.7 ± 1.4° in the LP only change group, and 2.6 ± 0.9° in the non-change group. A previous study [25] reported that pelvic range of motion during gait in the healthy adults was 2.4 ± 1.0° as in this study. Since pelvic range of motion during gait is small, the difference of 2.0° of ΔPelvis between the LP and LBP change group and LP only change group is considered to be very large.

During gait, the pelvis plays two roles: locomotor and passenger system [26]. While the pelvis is a mobile link between two lower limbs as part of the locomotor system, it also serves as the bottom segment of the passenger unit that rides on the hip joints. As it plays an important role during gait, it might be necessary to prevent the increase of anterior pelvic tilt to reduce LBP during gait. In the future, studies involving some intervention at the pelvis are needed to decrease LBP during gait in LSS patients. Furthermore, the ODI scores of the LP and LBP change and LP only change groups were 50% and 41%, respectively. The ODI score of level of function corresponds to a percentage of disability whereby a score of 41–60% = severe disability [12, 13]; thus, our subjects had severe disability. It is also necessary to compare the data according to the severity of disability in order to confirm whether our results are applicable to only LSS patients with severe disability or to all LSS patients.

In this study, the peak anterior trunk tilt during the stance phase pre-effort was negatively correlated with ΔLP. A previous study also showed that the association of a smaller anterior trunk tilt (the sum of the thoracic and lumbar tilts) with higher VAS scores for LP were observed in patients with LSS preoperatively [18]. That is, the aggravation of LP after gait loading might be induced by less anterior tilts both in the pre-effort thoracic and lumbar spines.

Before gait loading, the association between a smaller anterior trunk tilt and ΔLP and between a smaller lumbar anterior tilt and ΔLBP were observed in the present study. That is, by analysing the trunk or lumbar spine movement at the start of walking, it is possible to determine whether leg or low back pain worsens. In the future study, these cut-off values should also be calculated.

Several limitations of this study should be noted. As this study was a cross-sectional study, cause-and-effect relationships between LBP and kinematics of the spine and pelvis can only be inferred. To clarify causal relationships, a longitudinal study should be conducted. Another limitation was that difficulty in selecting patients who were capable of performing the selected tasks and obtaining three-dimensional gait analysis led to a small sample size.

In conclusion, even in patients with LSS who had no worsened LP after gait loading, the anterior tilt of the lumbar region still increased, but not that of the whole spine or thoracic region. Our findings suggest that gait analysis for LSS patients using gait loading test should be conducted to focus on the lumbar movement. Furthermore, the smaller lumbar anterior tilt of LSS patients regardless of gait loading and the larger anterior pelvic tilt after gait loading may affect the aggravation of LBP by gait loading. Therefore, increase in the lumbar lordosis might be one of the factors leading to LBP during gait in LSS patients.

Conflict of interest

The authors declare that they have no conflict of interest.

Acknowledgements

The authors thank Professor Hiroaki Kimura, Department of Rehabilitation, Hiroshima University Hospital for his assistance in the preparation of this manuscript.

References

[1] Katz JN, Harris MB. Clinical practice. Lumbar spinal stenosis. N Engl J Med 2008 Feb;358(8):818-25.

[2] Suri P, Rainville J, Kalichman L, Katz JN. Does this older adult with lower extremity pain have the clinical syndrome of lumbar spinal stenosis? JAMA 2010 Dec;304(23):2628-36.

[3] Takahashi K, Miyazaki T, Takino T, Matsui T, Tomita K. Epidural pressure measurements. Relationship between epidural pressure and posture in patients with lumbar spinal stenosis. Spine 1995 Mar;20(6):650-3.

[4] Suda Y, Saitou M, Shibasaki K, Yamazaki N, Chiba K, Toyama Y. Gait analysis of patients with neurogenic intermittent claudication. Spine 2002 Nov;27(22):2509-13.

[5] Nagai K, Aoyama T, Yamada M, Izeki M, Fujibayashi S, Takemoto M, Nishiguchi S, Tsuboyama T, Neo M. Quantification of changes in gait characteristics associated with intermittent claudication in patients with lumbar spinal stenosis. J Spinal Disord Tech 2014 Jun;27(4):E136-42.

[6] Garbelotti SA Jr, Lucareli PR, Ramalho A Jr, de Godoy W, Bernal M, D'Andréa Greve JM. An investigation of the value of tridimensional kinematic analysis in functional diagnosis of lumbar spinal stenosis. Gait Posture 2014;40(1):150-3.

[7] Miyakoshi N, Hongo M, Kasukawa Y, Ishikawa Y, Shimada Y. Prevalence, Spinal Alignment, and Mobility of Lumbar Spinal Stenosis with or without Chronic Low Back Pain: A Community-Dwelling Study. Pain Res Treat 2011;2011:340629.

[8] Jones AD, Wafai AM, Easterbrook AL. Improvement in low back pain following spinal decompression: observational study of 119 patients. Eur Spine J 2014 Jan;23(1):135-41.

[9] Lee CS, Chung SS, Kang KC, Park SJ, Shin SK. Normal patterns of sagittal alignment of the spine in young adults radiological analysis in a Korean population. Spine 2011 Dec;36(25):E1648-54.

[10] Fukuhara S, Bito S, Green J, Hsiao A, Kurokawa K. Translation, adaptation, and validation of the SF-36 for use in Japan. J Clin Epidemiol 1998 Nov;51(11):1037-44.

[11] Laucis NC, Hays RD, Bhattacharyya T. Scoring the SF-36 in Orthopaedics: A Brief Guide. J Bone Joint Surg Am 2015 Oct;97(19):1628-34.

[12] Fairbank JC, Couper J, Davies JB, O'Brien JP. The Oswestry low back pain disability questionnaire. Physiotherapy 1980 Aug;66(8):271-3.

[13] Fairbank JC, Pynsent PB. The Oswestry Disability Index. Spine 2000 Nov;25(22):2940-52.

[14] McLoughlin JV, Barr CJ, Crotty M, Sturnieks DL, Lord SR. Six minutes of walking leads to reduced lower limb strength and increased postural sway in people with Multiple Sclerosis. NeuroRehabilitation 2014;35(3):503-8.

[15] McLoughlin JV, Barr CJ, Patritti B, Crotty M, Lord SR, Sturnieks DL. Fatigue induced changes to kinematic and kinetic gait parameters following six minutes of walking in people with multiple sclerosis. Disabil Rehabil 2016;38(6):535-43.

[16] Bellamy N, Carette S, Ford PM, Kean WF, le Riche NG, Lussier A, Wells GA, Campbell J. Osteoarthritis antirheumatic drug trials. III. Setting the delta for clinical trials--results of a consensus development (Delphi) exercise. J Rheumatol 1992 Mar;19(3):451-7.

[17] Kim SH, Kwon OY, Yi CH, Cynn HS, Ha SM, Park KN. Lumbopelvic motion during seated hip flexion in subjects with low-back pain accompanying limited hip flexion. Eur Spine J 2014 Jan;23(1):142-8.

[18] Kuwahara W, Deie M, Fujita N, Tanaka N, Nakanishi K, Sunagawa T, Asaeda M, Nakamura H, Kono Y, Ochi M. Characteristics of thoracic and lumbar movements during gait in lumbar spinal stenosis patients before and after decompression surgery. Clin Biomech 2016 Dec;40:45-51.

[19] Gombatto SP, Brock T, DeLork A, Jones G, Madden E, Rinere C. Lumbar spine kinematics during walking in people with and people without low back pain. Gait Posture 2015 Oct;42(4):539-44.

[20] Atkinson G, Nevill AM. Statistical methods for assessing measurement error (reliability) in variables relevant to sports medicine. Sports Med 1998 Oct;26(4):217-38.

[21] Inufusa A, An HS, Lim TH, Hasegawa T, Haughton VM, Nowicki BH. Anatomic changes of the spinal canal and intervertebral foramen associated with flexion-extension movement. Spine 1996 Nov;21(21):2412-20.

[22] Kang MH, Kim ER, Kim YG, Kim TH, Oh JS. The effects of lumbo-pelvic postural taping on gait parameters in patients with lumbar spinal stenosis. Clin Biomech 2013 Nov-Dec;28(9-10):956-60.

[23] Levine D, Whittle MW. The effects of pelvic movement on lumbar lordosis in the standing position. J Orthop Sports Phys Ther 1996 Sep;24(3):130-5.

[24] Shirazi-Adl A, Drouin G. Load-bearing role of facets in a lumbar segment under sagittal plane loadings. J Biomech 1987;20(6):601-13.

[25] MacWilliams BA, Rozumalski A, Swanson AN, Wervey R, Dykes DC, Novacheck TF, Schwartz MH. Three-dimensional lumbar spine vertebral motion during running using indwelling bone pins. Spine 2014;39(26):E1560-5.

[26] Perry J, Burnfield JM. Gait analysis: Normal and Pathological Function, 2nd edn. New Jersey: Slack Incorporated; 2010, p. 19-22.

Figure captions

Fig. 1 A flow diagram describing the protocol used. SF-36, MOS 36-Item Short-Form Health Survey; ODI, Oswestry Disability Index; VAS, Visual Analogue Scale, pre-effort, before gait loading test; post-effort, after gait loading test.

Fig. 2 Definition of the T1, L1, and Pelvic segments. C7, T1, T12, and L1 show each spinous process. R- and L- T1, L1, ASIS, and PSIS show the right and left sides of the spinous process of T1, L1, and the anterior and posterior superior iliac spines, respectively.

Fig. 3 Temporal changes in trunk, thoracic, lumbar and pelvic tilting movements during one gait cycle, before and after the gait loading test. Error bars showed standard deviation. One gait cycle was defined as the period from the initial contact of the right leg to the next initial contact of the same leg. LP and LBP change, LP only change, and non-change groups were divided based on leg and low back pains according to the visual analogue scale after gait loading compared to before test. Pre-effort and post-effort show before and after gait loading test, respectively. The red, blue, green, smooth, and dashed lines show the mean trace of the LP and LBP change, LP only change, and non-change groups, pre-effort and post-effort, respectively.

Table 1 Patients' demographics, walking distance, clinical outcomes and pain

	LP and LBP change (n = 8)	LP only change (n = 12)	non-change (n = 9)	*p*
Age (years)	72 ± 7	69 ± 8	71 ± 9	0.650
Body height (m)	1.55 ± 0.07	1.60 ± 0.09	1.59 ± 0.08	0.569
Body weight (kg)	57.9 ± 8.6	60.5 ± 8.8	58.6 ± 11.3	0.820
Body mass index (kg/m^2)	24.2 ± 4.6	23.8 ± 3.4	23.3 ± 4.2	0.897
Sex (male:female)	4:4	9:3	4:5	0.314
Walking distance (m)	289 ± 45	277 ± 77	346 ± 79	0.082
SF-36				
Physical functioning	36.9 ± 20.0	47.9 ± 19.9	53.9 ± 13.6	0.157
Role physical	39.1 ± 24.9	56.3 ± 27.2	53.5 ± 21.5	0.311
Bodily pain	31.5 ± 10.4	40.3 ± 23.0	45.1 ± 13.6	0.159
General health perception	35.8 ± 13.3	42.0 ± 13.5	48.7 ± 16.2	0.210
Vitality	44.6 ± 18.1	41.7 ± 23.9	45.2 ± 20.4	0.924
Social functioning	59.4 ± 20.9	61.5 ± 22.9	65.3 ± 25.6	0.635
Role emotional	43.8 ± 32.7	60.3 ± 26.0	57.4 ± 20.2	0.381
Mental health	59.4 ± 15.0	53.8 ± 20.0	60.6 ± 17.4	0.573
ODI (%)	50 ± 12	41 ± 13	35 ± 12	0.066
VAS (mm)				
Leg pain pre-effort	36 ± 26	36 ± 24	17 ± 22	0.524
Leg pain post-effort	68 ± 28 [¶¶]	54 ± 25 [¶¶]	13 ± 14	**< 0.001**
Low back pain pre-effort	28 ± 21	22 ± 22	14 ± 17	0.160
Low back pain post-effort	62 ± 23 [†, ¶¶]	28 ± 26	13 ± 16	**0.002**

Values are mean ± standard deviation. LP and LBP change, group with worsened leg and low back pains after gait loading test; LP only change, group with worsened leg pain only after gait loading test; non-change, group with no changes in leg and low back pains after gait loading test; walking distance, walking distance of the gait loading test; SF-36, MOS 36-Item Short-Form Health Survey; ODI, Oswestry Disability Index; VAS, Visual Analogue Scale; pre-effort, before gait loading test; post-effort, after gait loading test.

†Significant differences from control group ($p < 0.05$).

¶¶Significant difference from LBP change - group ($p < 0.01$).

Table 2 Spatiotemporal and kinematic parameters during gait before and after gait loading test

	LP and LBP change (n = 8)		LP only change (n = 12)		non-change (n = 9)		Group effect (p)	Time effect (p)	Group × time interaction (p)
	pre-effort	post-effort	pre-effort	post-effort	pre-effort	post-effort			
Velocity (m/min)	46.5 ± 7.5	52.6 ± 8.0	50.5 ± 12.2	52.2 ± 14.9	55.6 ± 15.3	62.0 ± 15.9	0.278	**< 0.001**	0.126
Cadence (step/min)	107.9 ± 9.6	115.3 ± 10.2	108.5 ± 12.9	113.7 ± 16.6	115.3 ± 8.5	118.3 ± 10.3	0.511	**< 0.001**	0.286
Stride length (% body height)	0.55 ± 0.07	0.58 ± 0.08	0.57 ± 0.12	0.57 ± 0.12	0.61 ± 0.15	0.66 ± 0.14	0.420	**0.009**	0.093
Kinematics (degree)									
Peak trunk tilt in stance	5.6 ± 3.8	6.0 ± 3.8	6.6 ± 4.2	8.3 ± 5.4	4.9 ± 1.9	4.4 ± 3.4	0.243	0.241	0.211
Peak thoracic tilt in stance	3.6 ± 4.0	4.0 ± 3.3	2.4 ± 3.1	2.6 ± 4.2	2.1 ± 3.4	1.4 ± 4.3	0.502	0.998	0.506
Peak lumbar tilt in stance	2.8 ± 2.4	3.3 ± 3.0	5.6 ± 3.4	7.0 ± 4.1	3.5 ± 2.5	4.0 ± 2.2	0.054	**0.021**	0.326
Peak pelvic tilt in stance	2.3 ± 1.3	3.7 ± 2.4 **	3.1 ± 3.2	2.5 ± 3.3	1.5 ± 2.0	1.2 ± 1.8	0.302	0.470	**0.003**

Values are mean ± standard deviation. Positive kinematic values indicated anterior tilt. LP and LBP change, group with worsened leg and low back pains after gait loading test; LP only change, group with worsened leg pain only after gait loading test; non-change, group with no changes in leg and low back pains after gait loading test; pre-effort, before gait loading test; post-effort, after gait loading test.

**Significant difference from pre-effort ($p < 0.01$).

Table 3 Amount of change between before and after gait loading test for pain, spatiotemporal and kinematic parameters during gait

	LP and LBP change (n = 8)	LP only change (n = 12)	non-change (n = 9)	*p*
ΔVAS (mm)				
ΔLeg pain	32 ± 25 [††]	18 ± 11 [††]	-4 ± 11	**< 0.001**
ΔLow back pain	34 ± 14 [††, ¶¶]	5 ± 5 [†]	-1 ± 5	**< 0.001**
ΔVelocity (m/min)	6.1 ± 4.4	1.7 ± 6.9	6.3 ± 4.7	0.126
ΔCadence (step/min)	7.4 ± 4.3	5.1 ± 6.9	3.0 ± 4.4	0.209
ΔStride length (% body height)	0.02 ± 0.04	0.00 ± 0.05	0.05 ± 0.05	0.093
ΔKinematics (degree)				
ΔTrunk	0.5 ± 3.2	1.7 ± 2.4	-0.4 ± 2.4	0.286
ΔThoracic spine	0.5 ± 1.9	0.0 ± 2.7	-0.7 ± 2.1	0.616
ΔLumbar spine	0.4 ± 1.9	1.4 ± 1.7	0.4 ± 1.3	0.388
ΔPelvis	1.4 ± 1.5 [††, ¶¶]	-0.6 ± 0.8	-0.3 ± 1.3	**0.002**

Values are mean ± standard deviation. Positive and negative kinematic values respect to pre-effort indicated anterior and posterior tilts, respectively. LP and LBP change, group with worsened leg and low back pains after gait loading test; LP only change, group with worsened leg pain only after gait loading test; non-change, group with no changes in leg and low back pains after gait loading test; Δ, amount of change between before and after gait loading test; VAS, Visual Analogue Scale.

[†] and [††]Significant differences from control at $p < 0.05$ and $p < 0.01$, respectively.

[¶¶]Significant differences from LBP change - at $p < 0.01$.

Table 4 Correlations between kinematics during gait and ΔLeg pain and ΔLow back pain in lumbar spinal stenosis patients except for the non-change group

	ΔLeg pain		ΔLow back pain	
Parameter	Correlation Coefficient (*r*)	*p*	Correlation Coefficient (*r*)	*p*
Velocity pre-effort	-0.206	0.384	-0.109	0.648
Velocity post-effort	-0.098	0.681	-0.103	0.667
ΔVelocity	0.112	0.638	0.081	0.736
Peak trunk tilt pre-effort	**-0.455**	**0.044**	-0.247	0.294
Peak trunk tilt post-effort	-0.170	0.475	-0.274	0.242
ΔTrunk	0.128	0.590	-0.188	0.427
Peak thoracic tilt pre-effort	-0.421	0.065	0.175	0.460
Peak thoracic tilt post-effort	-0.187	0.430	0.082	0.731
ΔThoracic spine	0.286	0.222	0.128	0.592
Peak lumbar tilt pre-effort	-0.103	0.665	**-0.508**	**0.022**
Peak lumbar tilt post-effort	-0.081	0.733	**-0.503**	**0.024**
ΔLumbar spine	-0.123	0.606	-0.225	0.340
Peak pelvic tilt pre-effort	-0.139	0.560	0.016	0.947
Peak pelvic tilt post-effort	-0.158	0.505	0.343	0.139
ΔPelvis	0.035	0.822	**0.506**	**0.023**

pre-effort, before gait loading test; post-effort, after gait loading test; Δ, amount of change between before and after gait loading test

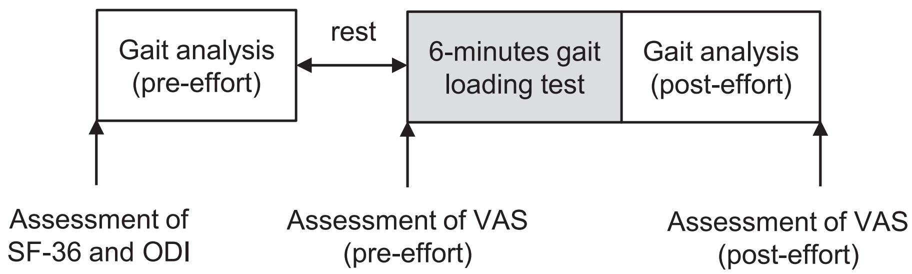
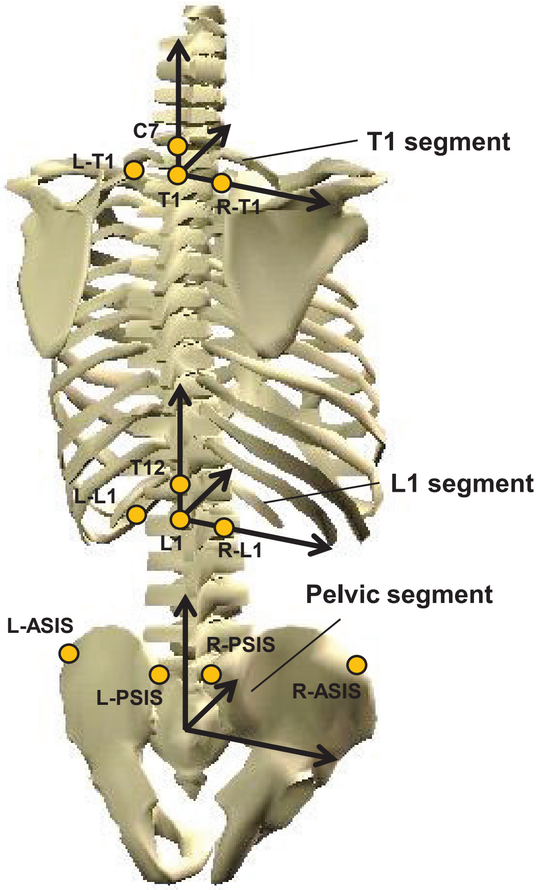

Gait analysis
(pre-effort)
rest
6-minutes gait
loading test
Gait analysis
(post-effort)
Assessment of
SF-36 and ODI
Assessment of VAS
(pre-effort)
Assessment of VAS
(post-effort)

Fig. 1



T1 segment
C7
L-T1
T1
R-T1
T12
L1 segment
L-L1
L1
R-L1
Pelvic segment
L-ASIS
R-PSIS
L-PSIS
R-ASIS

Fig. 2

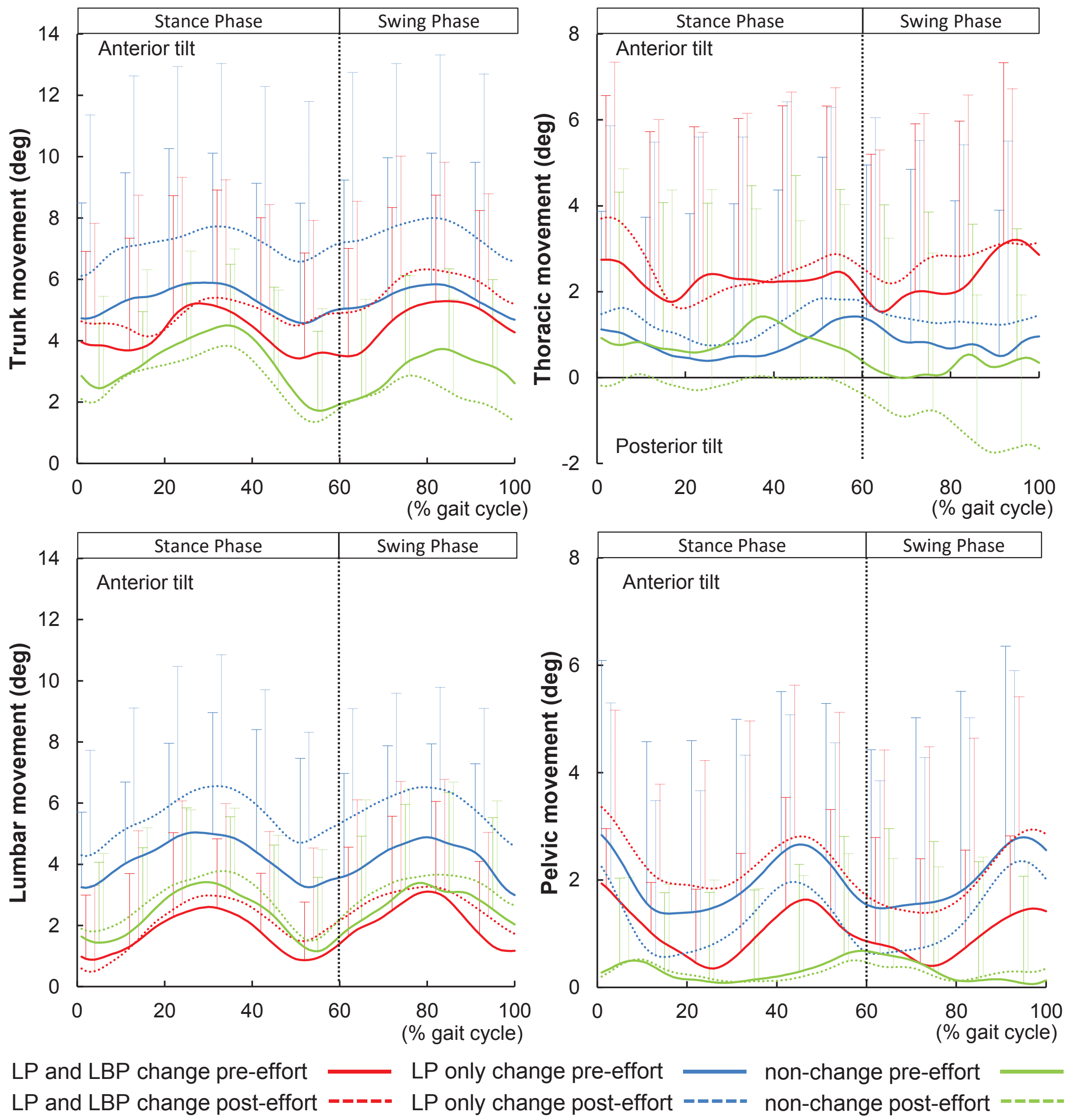

Stance Phase
Swing Phase
Anterior tilt
Trunk movement (deg)
14
12
10
8
6
4
2
0
0
20
40
60
80
100
(% gait cycle)
Stance Phase
Swing Phase
Anterior tilt
Posterior tilt
Thoracic movement (deg)
8
6
4
2
0
-2
0
20
40
60
80
100
(% gait cycle)
Stance Phase
Swing Phase
Anterior tilt
Lumbar movement (deg)
14
12
10
8
6
4
2
0
0
20
40
60
80
100
(% gait cycle)
Stance Phase
Swing Phase
Anterior tilt
Pelvic movement (deg)
8
6
4
2
0
0
20
40
60
80
100
(% gait cycle)
LP and LBP change pre-effort
LP and LBP change post-effort
LP only change pre-effort
LP only change post-effort
non-change pre-effort
non-change post-effort

Fig. 3