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ORIGINAL ARTICLE

Lumbar spine posture and spinopelvic parameters change in various standing and sitting postures

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Abstract

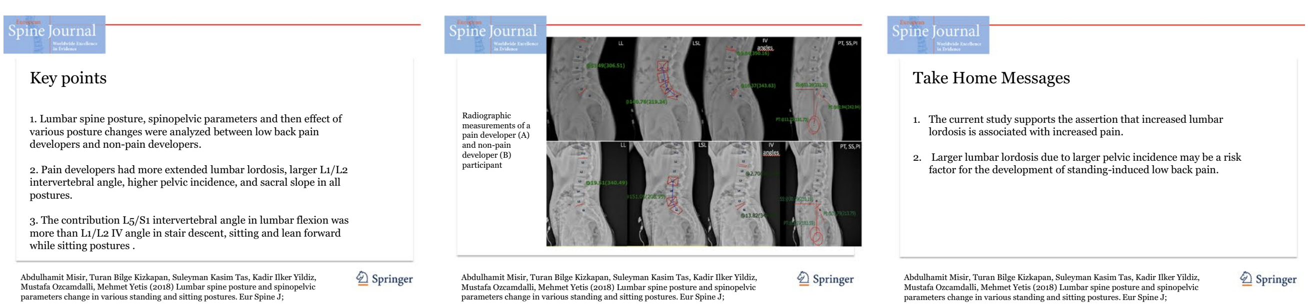
Purpose This study aimed to compare differences in lumbosacral and spinopelvic parameters between pain developers and non-pain developers as well as the effects of various posture changes.

Methods A total of 38 consecutive participants, 20 standing-induced low back pain developers (mean age: 27.7 ± 5.3; mean BMI: 22.64 ± 2.95) and 18 non-pain developers (mean age: 29.0 ± 7.5; mean BMI: 24.2 ± 1.87) ($p > 0.05$), were prospectively evaluated. Six sagittal plane radiographs were taken. Upright standing posture was used as the reference posture. Lumbar lordosis, lumbosacral lordosis, L1/L2 and L5/S1 intervertebral (IV) joint angles, pelvic incidence, pelvic tilt and sacral slope were measured on each radiograph.

Results There were no significant differences in terms of age, BMI, SF-36 score, or Oswestry Disability Index scores between pain developer and non-pain developer groups ($p > 0.05$). Pain developers had significantly larger lumbar lordosis, larger L1/L2 intervertebral angles, larger pelvic incidences and sacral slopes in all postures ($p < 0.05$). The contribution of L5/S1 intervertebral angle to lumbar flexion was higher than that of the L1/L2 intervertebral angle during stair descent, the sitting and the leaning forward while sitting postures ($p < 0.05$).

Conclusion The current study supports the assertion that increased lumbar lordosis is associated with increased pain. Lumbar spine angles change in various postures. The changes were more prominent in pain developers than in non-pain developers. Larger lumbar lordosis due to larger pelvic incidence may be a risk factor for the development of standing-induced low back pain.

Graphical abstract These slides can be retrieved under Electronic Supplementary Material.



Keywords Low back pain · Pain developer · Lumbar Posture · Spinopelvic · Standing-induced

Electronic supplementary material The online version of this article (https://doi.org/10.1007/s00586-018-5846-z) contains supplementary material, which is available to authorized users.

Extended author information available on the last page of the article

Introduction

Prolonged static postures such as standing while working and daily activities have been associated with low back pain (LBP) [1, 2]. Some individuals may be identified as LBP developers who have had no previous chronic LBP but who develop pain during prolonged standing periods [3]. Transient pain while standing has been considered a preclinical condition associated with future LBP [4].

Increased lumbar lordosis (LL) in the prolonged standing position has been reported to be a possible risk factor for LBP [5]. However, maximum extension angle did not differ between pain developers and non-pain developers. Furthermore, pain developers stand with more thoracic extension during prolonged standing [6]. Greater variability of the distal LL may mean that there are regional differences between pain developers and non-pain developers during level ground standing [7]. Due to changes in ground reaction forces, changing lower limb posture influences pelvic and lumbar spine posture. The pelvis and lumbar spine adapt in accordance with the degree of pelvic tilt (PT) and LL [8]. Rotation of the pelvis affects lumbar spine angles, such as posterior tilting of the pelvis results in lumbar flexion and anterior tilting results in lumbar extension [9]. Decreased trunk-thigh angle (hip flexion) causes posterior pelvic rotation and flattening of the lumbar spine [10].

In prolonged standing conditions, the most recommended positions are elevating one leg onto a surface or a bar and using a sloped surface [11, 12]. Elevation of one leg onto a surface causes trunk and lumbar spine flexion [13, 14]. When standing with ankle plantar flexion, posterior rotation of the pelvis and flattening of the lumbar spine is seen [3]. No significant difference in lumbar spine posture was reported when using a sloped standing aid compared to level ground standing [14].

Changes in lumbar and spinopelvic parameters in various daily postures must be investigated in order to develop effective approaches to prevent LBP developer status. This study aimed to examine sagittal lumbosacral and spinopelvic parameter differences between prolonged standing-induced LBP developers and non-LBP developers using radiographs and to compare changes in lumbosacral and spinopelvic parameters in various sitting and standing postures between standing-induced LBP developers and non-LBP developers.

Methods

Participant information

After the study was approved by the appropriate ethics review board and the participants provided informed consent, a total of 38 participants between 18 and 35 years old (24 males and 14 females; mean age: 28.4 ± 5.13; mean BMI: 23.4 ± 2.35), 20 LBP developers and 18 non-LBP developers, were included in this study (Table 1). All participants were healthy except for having standing-induced LBP. Low back pain developer status was defined according to a previously described procedure [7]. This procedure was as follows: a participant stood in a constrained posture while performing an occupational task such as working at a computer or performing a mock assembly. During this simulation, a participant responded to a 100-mm visual analog scale (VAS) in answer to the question, "What is your current level of low back pain?" The anchors of the VAS were "No pain at all" and "Worst pain imaginable." The scale was filled out every 7.5 min. A pain developer was identified by demonstrating an increase in VAS score of 10 mm from baseline. The 10-mm threshold was based on the 8-mm clinical difference for patients to feel their LBP worsening [15]. After repeated simulations 4 weeks apart, 85% of participants were characterized in the same pain groups [16]. Patients were selected from among those not previously exposed to X-rays in the last 12 months, except for an upright standing lateral lumbar radiograph. Exclusion criteria were as follows: previous history of LBP that required medical treatment or time off from work longer than 3 days; previous lumbar, lower extremity or abdominal surgery; employment in a task with prolonged static standing during the last 12 months; inability to stand for at least 2 h; current medical and psychological disorder that may affect low back pain; and female patients with any possibility of pregnancy. The SF-36 score and Oswestry Disability Index (ODI) were used in the evaluation of health-related quality of life. Our Institutional

Table 1 Age, BMI and SF-36 score details of participants

	PDs ($n=20$) Mean (SD)	Non-PDs ($n=18$) Mean (SD)	p value
Age (year)	27.7 (5.3)	29.0 (7.5)	0.682[m]
BMI (kg/m^2)	22.64 (2.95)	24.2 (1.87)	0.593[m]
SF-36 score (Total)	77.7 (22.5)	68.5 (21.2)	0.285[m]
ODI	25.0 (15.5)	28.0 (14.1)	0.593[m]

[m]Mann–Whitney U test

BMI body mass index, *PDs* pain developers, *SF-36* short form-36, *ODI* Oswestry disability index

Research Ethics Committee approved this study (2017-17/210) and written informed consent was obtained from all participants.

Radiographic instrumentation

Radiographs were taken with a diagnostic high-voltage generator machine (RESCUE 4UD, Kanit Medikal, Ankara, Turkey) by an experienced licensed technician. The central X-ray tube was directed perpendicular to the participant, 2.5 cm superior to the iliac crest and 1 cm posterior to the mid-axillary line [17]. The collimation was set to include T12 superiorly and the distal coccyx inferiorly. Technique factors were individually adjusted to the thickness of participant's trunk and pelvis. For this study, the technique factors were 80 kV-p (kilovolt peak) and 58 mA-s (milliampere-seconds) on average, yielding an average entrance dose of 704 mRem, beneath the maximum dose limit of 2000 mRem for lateral lumbar radiographs [18]. The typical effective dose for lateral lumbar radiograph was 30 mRem [18]. When taking several X-rays, the effective dose was the sum of the effective doses for each radiograph [18]. Therefore, the effective dose for this radiographic examination was a maximum 150 mRem (1.5 mSv; maximum of five X-rays allowed from the ethical review). This was comparable to the natural background radiation that a person is exposed to over 5 months [19]. Ten mSv effective dose may be associated with an increase in the possibility of fatal cancer by 0.05% [20].

Protocol

Radiographs in five postures were taken for each participant (Fig. 1).

1. Stair climbing posture: Standing with one foot raised onto a platform to represent the most likely posture when using this standing height. The height of the platform was adjusted so that a participant's thigh-to-trunk angle was 135°. This position has been shown to produce a physiologically normal lumbar curvature [10]. The thigh-to-trunk angle was measured clinically using a goniometer.
2. Stair descent posture: One of the participant's hips and knees were in a straight position, and the contralateral hip was in 30° flexion, and the knee was in 45° flexion with a straight trunk.
3. Maximum lumbar spine extension posture: The participant was told to keep their knees locked and to bend backward about their lumbar spine without shifting their hips forward.
4. Sitting posture: The participants were told to keep their hips and knees at 90° flexion with a straight trunk.
5. Lean forward while sitting posture: The participants were told to keep their knees at 90° and hips at 120° of flexion.

The order of the radiographs was randomized. The last radiograph taken was always in the maximum lumbar spine extension position. The upright standing position was the baseline posture for comparison.

For all radiographs, participants stood with their arms replicating the posture required to perform a light or computer assembly task and positioned their neck to gaze at their hands. To prevent superimposition of the diaphragm over the vertebral bodies of the upper lumbar spine, we captured the radiographs during suspended expiration [7].

Lumbopelvic angle measurements

Radiographic measurements were taken by Infinitt PACS System (Infinitt Healthcare Co, Seoul, South Korea). LL, lumbosacral lordosis (LSL), L1/L2 and L5/S1 angles were measured with the techniques described previously (Fig. 2) [7, 21]. Sacral slope (SS), PT and pelvic incidence (PI) were measured with the technique of Chung et al. [22]. All

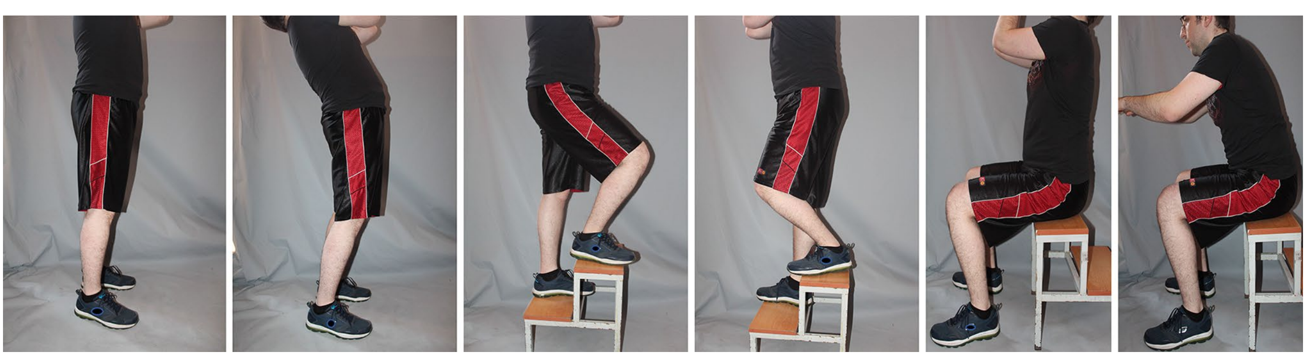


Fig. 1 Examples of the standing and sitting postures (from left to right): level ground, maximum lumbar spine extension, stair climbing, stair descent, sitting and leaning forward while sitting

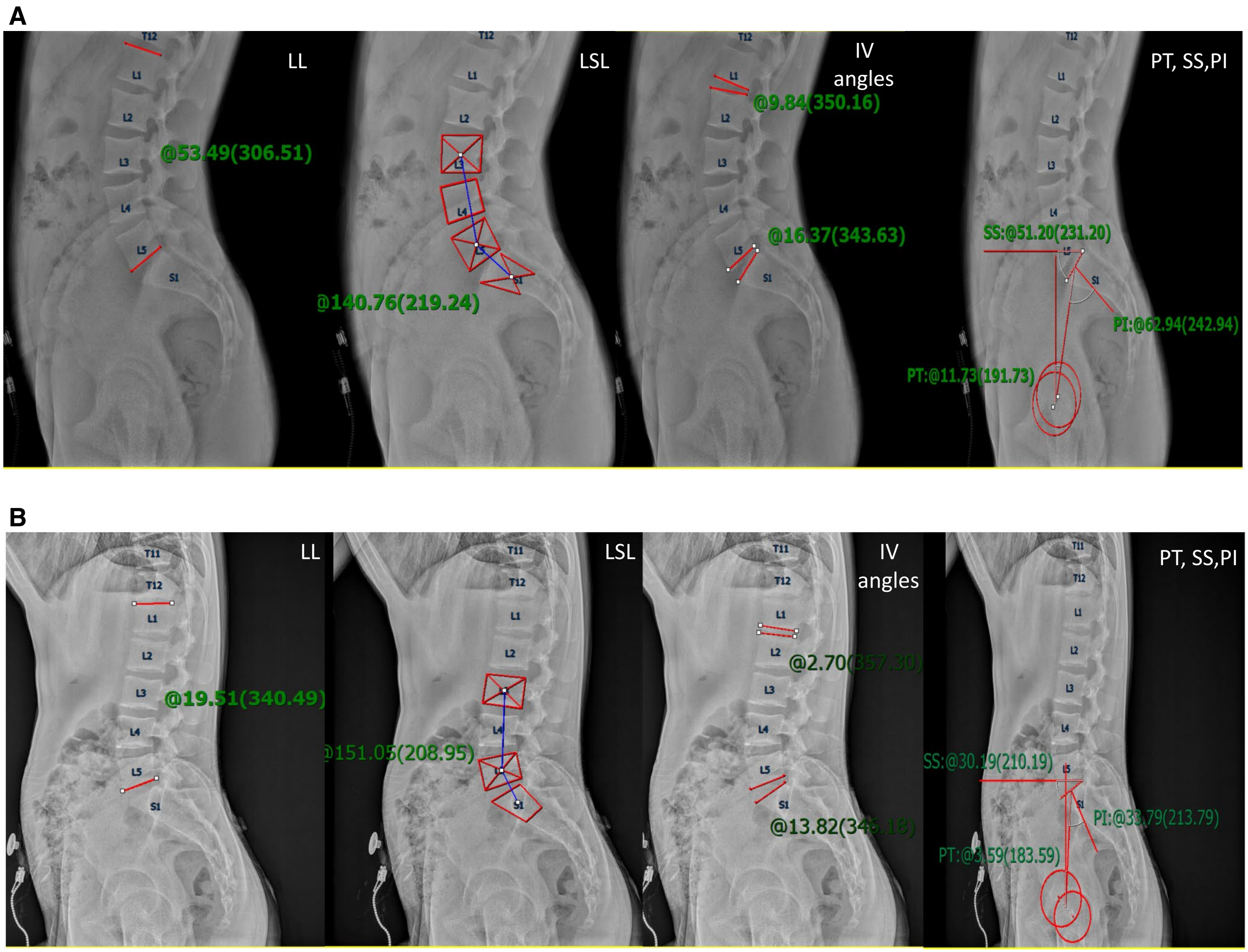


Fig. 2 Radiographic measurements of a pain developer (**a**) and a non-pain developer (**b**)

measurements were taken by an orthopedic surgeon who was blinded to participant pain status and the order of the radiographs.

Statistical analysis

Mean, standard deviation, median lowest, highest, frequency and ratio values were used in the descriptive statistics of the data. The Kolmogorov–Smirnov test was used to evaluate the distribution of variables. The Mann–Whitney U test was used for the analysis of independent quantitative data. The effect size was calculated with Cohen's d statistics, in which the pooled standard deviation was used [23]. The effect size is helpful to indicate how significant is the role of the conditions of the independent variable in determining results on the dependent variable. Therefore, it is an estimate of the effect of the independent variable, regardless of the sample size. The influence of the independent variable becomes more consistent with larger effect size. A Cohen's *d* of 0.2 or lower indicates weak, 0.2–0.45 indicates weak to moderate, 0.45–0.65 indicate moderate, 0.65–0.80 indicates moderate to strong and 0.80 or above indicates strong or high practical significance [23]. A *p* value of <0.05 was considered statistically significant. All statistical analyses were performed using SPSS IBM Statistics 22 (IBM, Armonk, New York, USA).

Results

There were no significant differences with respect to age, BMI, SF-36 score and Oswestry Disability Index score between the pain developer and non-pain developer groups ($p>0.05$) (Table 1).

We found that the mean values of LL, L1/L2 IV angle, PI and SS were significantly larger in the pain-developer group than in the non-pain developer group (all $p<0.05$) (Table 2).

Table 2 Comparative lumbosacral and spinopelvic radiographic measurements of participants

	PDs ($n=20$) Mean (SD)	Non-PDs ($n=18$) Mean (SD)	p value
LL	53.7 (20.7)	38.1 (15.8)	**0.000**^{m}
LSL	138.8 (10.5)	139.2 (9.4)	0.729^{m}
L1/L2 IV angle	7.3 (3.5)	4.9 (2.8)	**0.000**^{m}
L5/S1 IV angle	10.7 (6.1)	10.3 (5.0)	0.776^{m}
Pelvic incidence	55.0 (9.3)	44.2 (9.1)	**0.000**^{m}
Pelvic tilt	16.7 (12.5)	17.6 (9.2)	0.465^{m}
Sacral slope	38.3 (13.6)	26.6 (11.3)	**0.000**^{m}

Bold values indicate statistical significance

^{m}Mann–Whitney U test

LL lumbar lordosis, *LSL* lumbosacral lordosis, *IV* intervertebral

Intra- and inter-group measurements of various postures were compared with upright standing posture measurements (Tables 3 and 4). According to intergroup differences, the mean LL angle of the pain-developer patients was significantly larger than that of the non-pain developer patients with respect to upright standing, maximum extension lateral, stair climbing, stair descent and sitting postures (all $p<0.05$). There were no significant differences in mean LSL in all postures between the groups. The L1/L2 IV angle was significantly larger in the pain-developer group for maximum extension lateral and sitting postures (both $p<0.05$). There were no significant differences in mean L5/S1 IV angle in all postures between the groups.

The mean PI value was significantly larger in the pain-developer group than in the non-pain developer group with respect to all different postures (all $p<0.05$). There were

Table 3 Intragroup changes in lumbosacral and spinopelvic parameters with postural changes of pain developers (PDs) and non-pain developers (non-PDs)

	Lumbar lordosis				Lumbosacral lordosis			
	PDs ($n=20$)		Non-PDs ($n=18$)		PDs ($n=20$)		Non-PDs ($n=18$)	
	Mean (SD)	p value	Mean (SD)	p value	Mean (SD)	p value	Mean (SD)	p value
Upright standing	62.0 (5.9)		43.9 (7.0)		134.1 (5.9)		134.8 (5.9)	
Stair climbing	67.7 (6.8)	0.174^{m}	41.5 (9.8)	0.508^{m}	134.6 (4.8)	0.940^{m}	137.4 (4.9)	0.508^{m}
Stair descent	57.9 (10.8)	0.364^{m}	44.3 (10.1)	**0.895**^{m}	136.8 (11.8)	0.880^{m}	135.4 (6.9)	0.895^{m}
Sitting	43.4 (15.1)	**0.007**^{m}	31.1 (14.3)	0.058^{m}	146.8 (8.0)	**0.001**^{m}	145.9 (7.0)	**0.003**^{m}
Lean forward while sitting	31.9 (25.0)	**0.008**^{m}	23.3 (15.5)	**0.009**^{m}	146.5 (7.8)	**0.008**^{m}	147.0 (9.8)	**0.009**^{m}
Maximum extension	75.0 (7.5)	**0.001**^{m}	53.8 (9.7)	**0.015**^{m}	127.2 (6.5)	**0.049**^{m}	130.4 (7.3)	0.171^{m}
	L1/L2 IV angle				L5/S1 IV angle			
	PDs ($n=20$)		Non-PDs ($n=18$)		PDs ($n=20$)		Non-PDs ($n=18$)	
	Mean (SD)	p value	Mean (SD)	p value	Mean (SD)	p value	Mean (SD)	p value
Upright standing	7.3 (3.6)		5.1 (1.9)		13.7 (5.5)		11.2 (2.4)	
Stair climbing	7.0 (3.8)	1.000^{m}	5.4 (2.7)	0.627^{m}	15.3 (7.8)	0.821^{m}	11.3 (4.7)	0.691^{m}
Stair descent	7.1 (3.7)	0.821^{m}	5.5 (4.2)	0.757^{m}	9.2 (3.9)	**0.049**^{m}	10.3 (4.8)	0.200^{m}
Sitting	7.7 (4.0)	0.762^{m}	4.3 (2.0)	0.269^{m}	6.9 (4.6)	**0.016**^{m}	7.2 (3.4)	**0.009**^{m}
Lean forward while sitting	5.9 (3.6)	0.545^{m}	3.3 (1.9)	0.058^{m}	6.6 (4.4)	**0.007**^{m}	7.8 (5.4)	0.085^{m}
Maximum extension	9.6 (2.0)	0.096^{m}	7.0 (3.3)	0.200^{m}	14.0 (3.0)	0.791^{m}	12.9 (5.3)	0.354^{m}
	Pelvic tilt				Sacral slope			
	PDs ($n=20$)		Non-PDs ($n=18$)		PDs ($n=20$)		Non-PDs ($n=18$)	
	Mean (SD)	p value	Mean (SD)	p value	Mean (SD)	p value	Mean (SD)	p value
Upright standing	16.0 (6.1)		16.6 (5.4)		39.9 (6.7)		26.8 (8.9)	
Stair climbing	11.8 (10.0)	0.406^{m}	13.8 (10.4)	0.757^{m}	47.9 (9.0)	**0.041**^{m}	31.2 (10.9)	0.453^{m}
Stair descent	12.9 (11.9)	0.450^{m}	14.0 (6.3)	0.200^{m}	36.2 (11.9)	0.326^{m}	28.4 (7.7)	0.691^{m}
Sitting	24.4 (13.4)	**0.041**^{m}	23.1 (9.9)	0.070^{m}	29.4 (12.9)	0.151^{m}	21.9 (9.2)	0.171^{m}
Lean forward while sitting	19.9 (14.4)	0.545^{m}	19.6 (9.7)	0.566^{m}	37.0 (18.3)	1.000^{m}	26.8 (12.5)	0.757^{m}
Maximum extension	25.4 (8.8)	**0.005**^{m}	23.6 (5.9)	**0.012**^{m}	29.5 (7.6)	**0.007**^{m}	19.0 (9.1)	0.070^{m}

Bold values indicate statistical significance

^{m}Mann–Whitney U test

Table 4 Intergroup changes in lumbosacral and spinopelvic parameters with postural changes of pain developers (PDs) and non-pain developers (non-PDs)

	Lumbar lordosis			Lumbosacral lordosis		
	PDs ($n=20$)	Non-PDs ($n=18$)	p value	PDs ($n=20$)	Non-PDs ($n=18$)	p value
	Mean (SD)	Mean (SD)		Mean (SD)	Mean (SD)	
Upright standing	62.0 (5.9)	43.9 (7.0)	**0.000**^{m}	134.1 (5.9)	134.8 (5.9)	1.000^{m}
Stair climbing	67.7 (6.8)	41.5 (9.8)	**0.000**^{m}	134.6 (4.8)	137.4 (4.9)	0.253^{m}
Stair descent	57.9 (10.8)	44.3 (10.1)	**0.018**^{m}	136.8 (11.8)	135.4 (6.9)	0.935^{m}
Sitting	43.4 (15.1)	31.1 (14.3)	**0.046**^{m}	146.8 (8.0)	145.9 (7.0)	0.806^{m}
Lean forward while sitting	31.9 (25.0)	23.3 (15.5)	0.462^{m}	146.5 (7.8)	147.0 (9.8)	1.000^{m}
Maximum extension	75.0 (7.5)	53.8 (9.7)	**0.000**^{m}	127.2 (6.5)	130.4 (7.3)	0.414^{m}
	L1/L2 IV angle			L5/S1 IV angle		
	PDs ($n=20$)	Non-PDs ($n=18$)	p value	PDs ($n=20$)	Non-PDs ($n=18$)	p value
	Mean (SD)	Mean (SD)		Mean (SD)	Mean (SD)	
Upright standing	7.3 (3.6)	5.1 (1.9)	0.288^{m}	13.7 (5.5)	11.2 (2.4)	0.221^{m}
Stair climbing	7.0 (3.8)	5.4 (2.7)	0.462^{m}	15.3 (7.8)	11.3 (4.7)	0.414^{m}
Stair descent	7.1 (3.7)	5.5 (4.2)	0.142^{m}	9.2 (3.9)	10.3 (4.8)	0.414^{m}
Sitting	7.7 (4.0)	4.3 (2.0)	**0.030**^{m}	6.9 (4.6)	7.2 (3.4)	0.624^{m}
Lean forward while sitting	5.9 (3.6)	3.3 (1.9)	0.102^{m}	6.6 (4.4)	7.8 (5.4)	0.624^{m}
Maximum extension	9.6 (2.0)	7.0 (3.3)	**0.042**^{m}	14.0 (3.0)	12.9 (5.3)	0.514^{m}
	Pelvic tilt			Sacral slope		
	PDs ($n=20$)	Non-PDs ($n=18$)	p value	PDs ($n=20$)	Non-PDs ($n=18$)	p value
	Mean (SD)	Mean (SD)		Mean (SD)	Mean (SD)	
Upright standing	16.0 (6.1)	16.6 (5.4)	0.744^{m}	39.9 (6.7)	26.8 (8.9)	**0.006**^{m}
Stair climbing	11.8 (10.0)	13.8 (10.4)	0.683^{m}	47.9 (9.0)	31.2 (10.9)	**0.003**^{m}
Stair descent	12.9 (11.9)	14.0 (6.3)	0.806^{m}	36.2 (11.9)	28.4 (7.7)	0.191^{m}
Sitting	24.4 (13.4)	23.1 (9.9)	0.870^{m}	29.4 (12.9)	21.9 (9.2)	0.191^{m}
Lean forward while sitting	19.9 (14.4)	19.6 (9.7)	1.000^{m}	37.0 (18.3)	26.8 (12.5)	0.165^{m}
Maximum extension	25.4 (8.8)	23.6 (5.9)	1.000^{m}	29.5 (7.6)	19.0 (9.1)	**0.027**^{m}

Bold values indicate statistical significance

^{m}Mann–Whitney U test

no significant differences in mean PT values in all postures between the groups. The mean SS value was significantly larger in the pain-developer group for upright standing, extension lateral and stair climbing postures (all $p<0.05$).

According to intragroup changes in the pain-developer group, the mean LL angle was significantly larger in the extension lateral posture [$p<0.05$, $d=1.926$; the increase was $13° \pm 7.89°$]. However, it was significantly smaller in the sitting and leaning forward while sitting postures ($p<0.05$, $d=1.622$ and $p<0.05$, $d=1.657$, respectively). The decreases were $18.6° \pm 9.82°$ and $30.1° \pm 21.6°$, respectively. In the non-pain developer group, the mean LL angle was significantly larger in the extension lateral posture ($p<0.05$, $d=1.170$; the increase was $9.9° \pm 3.54°$). It was significantly smaller in the leaning forward while sitting postures ($p<0.05$, $d=1.712$), and the decrease was $20.6° \pm 6.28°$. In the pain-developer group, the mean LSL angle was significantly smaller in the extension lateral posture ($p<0.05$, $d=1.111$; the decrease was $6.9° \pm 4.08°$). It was significantly larger in the sitting and lean forward while sitting postures ($p<0.05$, $d=1.806$ and $p<0.05$, $d=1.793$, respectively). The increases were $14.7° \pm 9.16°$ and $14.3° \pm 5.70°$, respectively. The LSL angle was significantly larger in the non-pain developer group for sitting and leaning forward while sitting postures ($p<0.05$, $d=1.714$ and $p<0.05$, $d=1.508$, respectively). The increases were $11.1° \pm 5.57°$ and $12.2° \pm 4.08°$. According to Cohen's effect size values (d), all changes above suggested high practical significance.

There were no significant differences in L1/L2 IV angle between pain-developer and non-pain developer groups for postural changes ($p>0.05$).

In the pain-developer group, the mean L5/S1 IV angle was significantly smaller in the stair descent, sitting and leaning forward while sitting postures ($p < 0.05$, $d = 0.943$; $p < 0.05$, $d = 1.341$; and $p < 0.05$, $d = 1.425$, respectively). The decreases were 4.5° ± 2.0°, 6.8° ± 4.64° and 7.1° ± 3.70°, respectively. Cohen's effect size values ($d = 0.943$, 1.341 and $d = 1.425$) suggested high practical significance. In the non-pain developer group, the mean L5/S1 IV angle was only significantly smaller in the sitting posture ($p < 0.05$, $d = 1.359$). The decrease was 4° ± 1.96°. Cohen's effect size value ($d = 1.359$) suggested high practical significance.

There were no significant differences in PI for all postures and both groups.

In the pain-developer group, the PT was significantly larger in maximum extension and sitting postures ($p < 0.05$, $d = 1.241$ and $p < 0.05$, $d = 0.806$; changes were 9.4° ± 13.5° and 8.4° ± 11.1°, respectively). The PT in the non-pain developer group was only significantly larger in maximum extension posture ($p < 0.05$, $d = 1.237$; the change was 7° ± 6.38°).

Finally, the SS in the pain-developer group was significantly smaller in the maximum extension posture [$p < 0.05$, $d = 1.451$; the change was 10.4° ± 9.20°] and significantly larger in the stair climbing posture [$p < 0.05$, $d = 1.008$; the change was 8° ± 5.9°]. In the non-pain developer group, there were no significant changes in the SS for any postural changes.

Discussion

Standing upright radiographs are usually used in the evaluation of LBP. Spinal and spinopelvic alignment parameters in the standing posture may not precisely address mechanical alignment changes because changes in the spine, pelvis and limb postures affect each other [24, 25]. In this study, we evaluated lumbar and spinopelvic alignment changes in standing-induced LBP participants and non-pain developer participants in various standing and sitting postures to assess mechanical changes. Previous studies of sagittal spinal alignment focused on lumbar alignment or lumbar and spinopelvic alignment with limited postures [7, 10, 26–33]. We evaluated inter- and intra-group changes in lumbosacral and spinopelvic parameters in various sitting and standing postures between prolonged standing-induced LBP developers and non-pain developers.

Pelvic parameters affect total sagittal balance. The greater PI is associated with greater SS and larger LL [34]. LL and PI are directly proportional [34]. More LL can be tolerated to balance spinal alignment in large PI conditions [34]. Our results suggest that pain developers (PDs) had significantly more extended LL and L1/L2 intervertebral angles at the sum of all postures. Additionally, they had larger PI and SS values in all postures.

There were no significant differences in mean PT values between the groups in the upright position. Maximum extension posture was associated with significantly more posterior PT than in the upright position. This was independent of pain group (58.7 vs. 42%, $p > 0.005$). Furthermore, sitting posture was associated with significantly more posterior PT than was observed in the upright position in the PD group.

Stair descent posture was associated with significantly more flexion in the lumbar and lower lumbar spine. LL, LSL and L5/S1 IV angles were significantly more flexed than during upright standing. This was independent of pain group. Leaning forward while sitting posture was associated with significantly more flexion in the lumbar spine. LL, LSL and L5/S1 IV angles were significantly more flexed than during upright standing posture. This was more prominent in the PD group than in the non-PD group. Stair climbing posture had no significant effect on lumbar posture. However, stair descent posture was associated with significantly more flexion in the L5/S1 IV angle in the PD group. The maximum extension posture was associated with significantly more extension in the LL and LSL but not in the L1/L2 IV angle and L5/S1 IV angle in the PD group. Only LL was significantly higher in the non-PD group. Our results are consistent those of with previous reports [35, 36].

PI is constant for each posture and gender. Standing or sitting postures do not affect PI [37]. In a manner consistent with the literature, we did not find any difference in PI between standing and sitting postures. A higher PI was associated with larger LL with the more sagittal orientation of facet joints [38]. As a result, increased contact forces on lower lumbar facet joints develop. This may be associated with low back pain. Other studies suggested that LL angle does not accurately represent the upper and lower lumbar spine; upper and lower LL angles have been defined as functionally independent [35, 36, 39–41]. We found that lower lumbar spine changes were prominent in stair descent, sitting and leaning forward while sitting postures for upright standing posture in PD participants.

Endo et al. [33] reported 50% lower LL and 25% higher PT in the sitting position compared with upright standing. We observed 30% lower LL and 52.5% higher PT in the PD group in the sitting posture than in the upright standing posture. In the non-PD group, we observed 29.7% lower LL and 39.1% higher PT was seen. According to De Carvalho et al. [32], the lumbar spine flexes and the pelvis rotates posteriorly in the sitting position. We also found flexed lumbar spines and posteriorly rotated pelvises in the sitting posture in both PD and non-PD participants.

In the sitting posture, the PD group demonstrated extended lumbar spines and posteriorly rotated pelvises in maximum extension posture with flexion of the lumbar spine and posteriorly rotated pelvis. Minimally extended lumbar spine and posteriorly rotated pelvis were observed in the stair climbing posture. Leaning forward while sitting posture was associated with more lumbar flexion and an anteriorly rotated pelvis than was the sitting posture. We found no uniform relationship between LL, PT and LSL in various standing and sitting postures. Sagittal spinal balance, hip and knee postures may affect these parameters. Changes in the non-PD group were less noticeable than those in the PD group.

Modulated lumbar multifidus muscle activity with lumbar curve changes in LBP-free individuals was recently shown [42]. However, participants with a history of prolonged sitting-induced LBP did not show changes in multifidus muscle activity with lumbar curve changes. Enhanced trunk muscle activation increases spine loading, possibly leading to structural changes. Therefore, changes in muscle activity may be associated with pain development, and correction of posture alone may not change muscle activity or pain status. Our findings of higher lumbar lordosis, L1/L2 IV angle, pelvic incidence and sacral slope may be associated with structural changes due to spine loading. Changes in lumbar spine posture and spinopelvic parameters with various standing and sitting postures without changes in pain status in our study support the findings of Claus et al. [42].

Suzuki et al. [43] reported that older adults had greater lumbar lordosis and sacral slope in the sitting posture than did young adults, and there was a weak correlation among lumbopelvic parameters. Their results support the notion that lower lumbopelvic mobility is expected in elderly persons from sitting to standing. In our study, we evaluated two sitting postures: sitting and leaning forward while sitting. Pain developers had more lumbar lordosis and sacral slope in both postures. In contrast to findings in elderly persons, we found no significant difference in lumbopelvic mobility from sitting to standing. This discrepancy may be related to lack of degenerative changes in our younger participants.

Close interaction between the spine, pelvis and lower extremities determines sagittal balance. Sagittal vertical axis (SVA) and pelvic tilt (PT) are the two main parameters in the assessment of compensation [44]. SVA reflects the dynamic response of the spine and PT reflects the dynamic response of the pelvis. Measurement of these dynamic parameters on static X-rays depends on patient position. As a result, critical discrepancies may be seen for the same patient. To overcome this position-related discrepancy, Obeid et al. [44] described a new spinopelvic parameter, global tilt that reflects both spinal and pelvic responses. Global tilt was shown to be less affected by patient position than was SVA or PT. In our study, we used PT to evaluate pelvic response and lumbar lordosis to evaluate the spinal response. Lateral lumbar radiographs are insufficient for SVA measurement. Global tilt may provide more accurate spinal and pelvic dynamic responses in various posture evaluations because its accuracy is free from position-related discrepancies.

In lumbar fusions without considering the degree of pelvic incidence, extreme changes in pelvic tilt and sacral slope may occur to achieve sagittal balance. Lower extremity joints may be affected if spinopelvic compensatory mechanisms fail to achieve sagittal balance. Lumbar muscle activity may be increased following these structural changes. As a result, low back pain may develop.

There are several limitations of this study. First, the relatively small sample size may yield relatively less meaningful statistical results. Second, two-dimensional radiographic evaluation of three-dimensional and dynamic processes may limit the evaluation of pathologic steps. Third, the relatively short standing period before image capture may not reflect changes following longer daily standing. Fourth, the participant's lifestyles were not evaluated. Their back pain may be affected by psychosocial stressors. Fifth, we used lateral lumbar radiographs; evaluation with full-spine radiographs and more spinal and pelvic parameters would provide more detailed information.

In conclusion, pain developers had significantly more extended LL, greater L1/L2 intervertebral angles, larger PI and SS in all postures. The current study supports the assertion that increased lumbar lordosis is associated with increased pain. Lumbar spine angles change in various postures. These changes are more prominent in pain developers. Larger lumbar lordosis due to larger pelvic incidence may be a risk factor for the development of standing-induced low back pain.

Compliance with ethical standards

Conflict of interest All authors declare that they have no conflict of interest.

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