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Review Article

The relationships between low back pain and lumbar lordosis: a systematic review and meta-analysis

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Abstract

BACKGROUND CONTEXT: Clinicians regard lumbar lordotic curvature (LLC) with respect to low back pain (LBP) in a contradictory fashion. The time-honored point of view is that LLC itself, or its increment, causes LBP. On the other hand, recently, the biomechanical role of LLC has been emphasized, and loss of lordosis is considered a possible cause of LBP. The relationship between LLC and LBP has immense clinical significance, because it serves as the basis of therapeutic exercises for treating and preventing LBP.

PURPOSE: This study aimed to (1) determine the difference in LLC in those with and without LBP and (2) investigate confounding factors that might affect the association between LLC and LBP.

STUDY DESIGN: Systematic review and meta-analysis.

PATIENT SAMPLE: The inclusion criteria consisted of observational studies that included information on lumbar lordotic angle (LLA) assessed by radiological image, in both patients with LBP and healthy controls. Studies solely involving pediatric populations, or addressing spinal conditions of nondegenerative causes, were excluded.

METHODS: A systematic electronic search of Medline, Embase, Cochrane Library, CINAHL, Scopus, PEDro, and Web of Science using terms related to lumbar alignment and Boolean logic was performed: (lumbar lordo*) or (lumbar alignment) or (sagittal alignment) or (sagittal balance). Standardized mean differences (SMD) and 95% confidence intervals (CI) were estimated, and chi-square and I^2 statistics were used to assess within-group heterogeneity by random effects model. Additionally, the age and gender of participants, spinal disease entity, and the severity and duration of LBP were evaluated as possible confounding factors.

RESULTS: A total of 13 studies consisting of 796 patients with LBP and 927 healthy controls were identified. Overall, patients with LBP tended to have smaller LLA than healthy controls. However, the studies were heterogeneous. In the meta-regression analysis, the factors of age, severity of LBP, and spinal disease entity were revealed to contribute significantly to variance between studies. In the subgroup analysis of the five studies that compared patients with disc herniation or degeneration with healthy controls, patients with LBP had smaller LLA (SMD: −0.94, 95% CI: −1.19 to −0.69), with sufficient homogeneity based on significance level of .1 (I^2=45.7%, p=.118). In the six age-matched studies, patients with LBP had smaller LLA than healthy controls (SMD: −0.33, 95% CI: −0.46 to −0.21), without statistical heterogeneity (I^2=0%, p=.916).

FDA device/drug status: Not applicable.

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CONCLUSIONS: This meta-analysis demonstrates a strong relationship between LBP and decreased LLC, especially when compared with age-matched healthy controls. Among specific diseases, LBP by disc herniation or degeneration was shown to be substantially associated with the loss of LLC.

Keywords: Age; Disc degeneration; Disc herniation; Low back pain; Lumbar lordosis; Sagittal alignment

Introduction

Lumbar lordotic curvature (LLC) is a unique structural characteristic of the normal human spine that is not apparent in the neonatal spine, but becomes progressively prominent as an individual develops and adopts upright posture [1,2]. Phylogenetically, LLC is considered the key structural adaptation to bipedalism [3]. It places the center of mass of the torso above the hip and enables the soft tissue around the spine to neutralize shear loads [4], while enhancing its capacity to bear gravitational force [5]. In this way, humans can maintain erect posture in everyday life in a stable and energy-conservative manner [6] with minimal mechanical stress.

In contrast to the biomechanical point of view that emphasizes the critical evolutionary role of the LLC for *Homo erectus*, an extremely opposing viewpoint in certain clinical fields depicts it as the fundamental cause of low back pain (LBP) [7,8]. Interestingly, an increased lumbosacral angle is known to augment the pressure on the posterior ligaments and facet joints, and ultimately causes LBP. The widespread belief that LLC is a cause of LBP is evidenced by the fact that most clinicians advise their patients to abolish lumbar lordosis to alleviate LBP. Flexion exercises, so-called Williams exercises, are well established and widely implemented in clinical fields for the conservative treatment of LBP [9–12].

The conflicting evidence and attitudes surrounding the functions of the LLC and its interactions with diseased spines are surprising. Loss of LLC is the most distinctive finding of the aging spine [13], and the prevalence of LBP increases with age [14]. The belief that the reduction of the LLC, a mechanism occurring naturally with aging, could be the solution to alleviate LBP appears irrational. Moreover, it is antithetical that LLC is simultaneously an essential component for ergonomic bipedality and the cause of LBP. Clearly, the aspect of causality in the relationship between LLC and LBP is poorly understood, which puts into serious question whether the therapeutic low back exercises used to reduce LLC are beneficial or, in reality, harmful.

The cause and effect relationship between LLC and LBP can only be elucidated by prospective studies that relate current LLC with future low back problems. However, literature regarding this matter is extremely sparse. The next best way to examine this issue in a literature review is to review observational studies that report LLC in both patients with LBP and healthy controls (HC). A previous systematic review pertaining to this subject, which involved a meta-analysis, concluded that LLC did not differ between subjects with and those without LBP [15]. However, the heterogeneity among studies included in this meta-analysis seems to have been underestimated. Additionally, this review dealt with studies that employed clinical measures, whereas radiological methods are more suitable for measuring the absolute parameters of LLC [16].

Because LBP is a very heterogeneous entity, a consistent tendency in the alterations of lumbar curvature in patients with LBP might not be easily revealed. Even in asymptomatic individuals, sagittal alignment of the spinopelvic complex is highly variable, and the differentiation of patients with LBP from healthy normal controls cannot be achieved by examining LLC only [17]. Nonetheless, the continued development and refinement of our understanding of the sagittal profile of the lumbar spine in patients with LBP have immense clinical significance, as they directly impact the design and implementation of corrective exercises.

This review was conducted to investigate whether a consistent and significant relationship exists between LLC and LBP. We sought to address mechanical or degenerative LBP, excluding LBP in the context of definite fractures; nonmechanical spinal conditions such as infection, neoplasia, and inflammation; and visceral diseases [18]. Spondylolisthesis and scoliosis were excluded because both are conditions associated with LBP that can transform the sagittal alignment of the spine without alteration of the LLC. We hypothesized the presence of significant differences in the LLC of people with and without LBP, and that these differences would be affected by age and gender of the participants, severity and chronicity of the LBP, and the spinal disease entity of the LBP group. Thus, we synthesized cross-sectional studies that compared LLC between the two populations. The aim of this study was to (1) determine the difference in LLC between patients with LBP and HCs, and (2) elucidate possible confounding factors that might affect the association between LBP and LLC.

Methods

The studies included in the current meta-analysis are observational studies using data from cross-sectional, case-control, or cohort designs. Because the observational approach does not require the experimental element of random allocation to an intervention and investigates the association between a certain characteristic and the outcome of interest, there are inherent potential biases in the original studies included in this systematic review. We intended to report on all the items recommended in Ref. [19].

Search strategies

The electronic search was independently performed by two physiatrists (SWC and CYL) who completed colloquiums held by Cochrane Korea or the National Evidence-Based Healthcare Collaborating Agency. Because LLC is a very specific measure that has little relevance to conditions not associated with LBP, we intended to check all studies that included any keywords related to LLC without any preconditions related to LBP. Studies on congenital, hereditary, developmental, or traumatic conditions were excluded. All titles, and abstracts or texts when necessary, were evaluated to verify that LLC was measured in both LBP and HC groups.

Relevant articles were identified by computerized searches of seven electronic databases (Medline, Embase, Cochrane Library, CINAHL, Scopus, PEDro, and Web of Science) from the date of inception to June 2016. The search was conducted using the following keywords: "lumbar lordo*", "lumbar alignment", "sagittal alignment", and "sagittal balance". Studies that contained terms related to congenital, hereditary, developmental, or traumatic conditions in the title were excluded. Filters were set to restrict the results to human studies that were published or in press in academic journals. The search was modified to accommodate the different methods of each database. The filtering process was repeated manually after duplicates were removed. We contacted the authors by email when we were uncertain whether to include or exclude the article. No language limitation was preset in the electronic search; however, inclusion was limited to studies written in Korean, Japanese, English, French, Spanish, and Portuguese because of availability of translation.

Selection criteria

After the comprehensive electronic search, studies were included if (1) they mainly consisted of adult subjects, (2) LLC was assessed by radiograph (eg, roentgenogram, magnetic resonance imaging, computed tomography), (3) LLC was measured as the angle between the end plates of two different lumbar vertebrae (lumbar lordotic angle [LLA]), (4) it could be inferred that spondylolisthesis and scoliosis were excluded, and (5) LLA was calculated in both the patient group and the control group. Exclusion criteria were as follows: (1) LBP etiology from secondary causes (eg, fractures, infections, malignancies, neurodegenerative diseases, etc.), (2) the absence of a statement that the control group was symptom free (eg, healthy volunteers), (3) a highly specific study population (eg, athletes, wheelchair-bound patients, patients with Scheuermann disease, etc.), (4) a clearly irrelevant topic (eg, "The Vertebral Column of *Australopithecus sediba*"), and (5) improper group comparison (eg, patients with disc herniation with and without LBP).

Quality assessment

The Newcastle-Ottawa Scale for case-control studies [20] was used to assess the risk of bias of individual studies. The Newcastle-Ottawa Scale is designed to evaluate the selection of subjects, group comparability, and ascertainment of exposure for case-control studies. Its score ranges from 0 to 9: less than 6 is considered low quality; less than 8, moderate quality; and 8 or more, high quality. Assessments were conducted by two authors (SWC and CYL), independently. In cases of disagreement, accordance was achieved by discussion or by a third author (SGC). Inter-rater reliability of the quality assessment was evaluated by two-way mixed interclass correlation coefficient statistics for absolute agreement using SPSS Statistics 23.0 (IBM Corp, Armonk, NY, USA).

Data extraction

A predefined list of elements that might affect LLC was formulated. Data regarding age, gender, and the definitions of both the LBP and the HC groups were included. Exclusion criteria, specific diagnosis, and duration and severity of LBP in the patient group were documented. We considered those patients scheduled for surgery as having severe LBP. For each study, the year of publication, study design (retrospective or prospective, case-control or cross-sectional), whether the patient and control groups were matched, country of origin, radiological methods used, position in which LLA was measured, and the anatomical structure adopted for measurement (eg, superior end plate of L1 and sacral plate) were recorded. The LLA was the outcome variable. The mean and standard deviation (SD) of LLA, and the number of subjects in both the LBP patient group and the HC group were coded. In studies that included patients with spondylolisthesis or scoliosis as a subgroup of the LBP group [21–23], the data on the remaining subjects after excluding the corresponding disease entities were synthesized and included. In a study that did not report the SD [24], the p-value of the group comparison was adopted. Two reviewers (SWC and CYL) coded the data independently, and the results were compared for consensus.

Statistical analysis

Standardized mean difference (SMD) was calculated by the difference in means between the LBP group and the HC group divided by the pooled SD. For studies that did not present the SD, SMD was estimated using the p-value. A 95% confidence interval (95% CI) was extracted from the pooled SD. Meta-analysis with random effects model was performed to infer the pooled estimate SMD, and statistical heterogeneity was assessed by the I^2 statistics and the chi-square test. Heterogeneity was investigated with random effects meta-regression, entering factors such as age, gender, disease entity, disease chronicity, pain severity, and results of the quality assessment as covariates. To reflect the ages of both the LBP group and the HC group, the age difference between the two groups was calculated. No study reported the LLA of both the LBP group and the HC group by gender, and the ratio of male and female patients in the LBP group and the HC group was coded. The age difference, gender ratios, and

the score of quality assessment were entered as continuous variables. Whether the LBP group had a specified spinal disease entity, chronic pain, or severe pain were entered as binary variables. Subsequent subgroup analysis was performed based on the factors that were proven significant in the regression model. Pooled estimates of overall difference were calculated when there was limited heterogeneity (p>.1) within the subgroup using random effects models. All analyses were conducted using Comprehensive Meta-Analysis software, version 3.3.070 (Biostat, Englewood, NJ, USA).

Results

Search and selection of studies

The initial electronic search identified 15,777 studies (Medline: 3,837, Cochrane Library: 291, EMBASE: 4,660, CINAHL: 67, Scopus: 3,952, Web of Science: 2,920, and PEDro: 50). We reviewed the titles of the remaining studies after removing 8,991 duplicates and another 1,188 articles that were comments, letters, conference presentations, etc. Among the remaining 5,598 studies, 5,186 pertained to a clearly irrelevant topic. There was one longitudinal study that investigated the relationship between current LLC and future incidence of LBP [25]. A total of 412 abstracts were screened and, ultimately, 242 were excluded (improper article type, 28; improper group definition, 67; single-arm design, 78; LLA not presented, 27; clinical measure, 22; irrelevant subject, 19; text not accessible, 1). We reviewed the full text of 170 articles and excluded 157 (improper article type, 20; improper group definition, 37; linguistic limitation, 3; clinical measure, 19; insufficient information, 73; shared participants, 5). As a result, a total of 13 articles were included in this review (Fig. 1) [21–24,26–34].

Characteristics of the included studies

The characteristics of the included studies are shown in Table 1. All studies were case-control design and they involved a total of 796 cases and 927 controls.

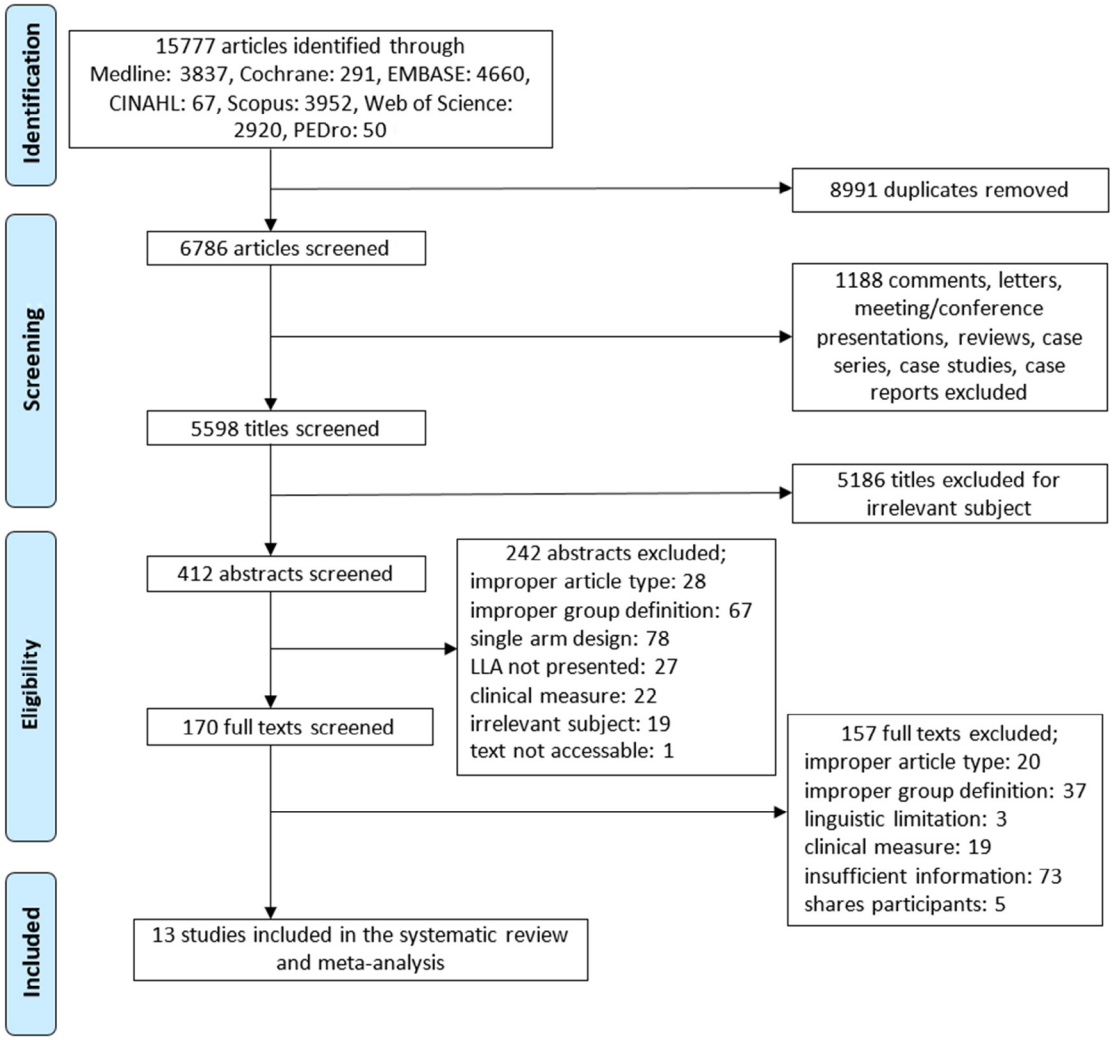

Fig. 1. Flow diagram of searched, screened, and included studies. LLA, lumbar lordotic angle.

Table 1
Summary of studies in the review

Study	Study design	Study population	Lumbar lordosis	LBP or HC definition	Excluded from LBP	Risk of bias
Jackson and McManus 1994 [29]	Prospective Case-control	N LBP(M:F)=100(50:50), mean age=39.4±8.95 y; N HC(M:F)=100(50:50), mean age=38.9±9.44 y; from USA	Measured by lateral radiograph Upright position – LE: knee extension Range: L1 SE–SP	Volunteers, LBP: LBP duration>6 wk HC: no LBP for 6 mo	Previous spinal surgery, spondylolytic spondylolisthesis, clinical deformity	5/9
Wood et al. 1996 [24]	Prospective Case-control	N LBP(M:F)=50(26:24), mean age=44.0 y; N HC(M:F)=50(22:28), mean age=40.1 y; from USA	Measured by lateral radiograph Upright position Range: L1 SE–SP	Volunteers LBP: LBP duration>6 wk HC: no LBP ever	Spondylolisthesis, fracture, infection, tumor of spine, previous spine surgery	5/9
Jackson et al. 1998 [22]	Prospective for HC, retrospective for LBP Case-control	N LBP(M:F)=110(45:65), mean age=37.91±10.18 y; N HC(M:F)=50(25:25), mean age=39.4±9.45 y; from USA	Measured by lateral radiograph Upright position – LE: knee extension Range: L1 SE–SP	LBP: symptomatic DDD, isthmic spondylolisthesis, scoliosis HC: no hip pain or LBP for 6 mo	Previous spine surgery, symptomatic hip disease, spondylolytic spondylolisthesis, clinical deformity	6/9
Korovessis et al. 1999 [31]	Prospective Case-control	N LBP=120, N HC=120, from Greece	Measured by lateral radiograph Upright position – UE: hands on bars in front Range: T12 IE–SP	LBP: LBP duration>2 mo HC: asymptomatic volunteers	Previous spine or hip surgery, spondylolysis, spondylolisthesis, traumatic deformity, scoliosis, congenital deformity, limb leg discrepancy	5/9
Tuzun et al. 1999 [33]	Case-control	N LBP(M:F)=100(24:76), mean age=45.95±16.08 y; N HC(M:F)=50(8:42), mean age=46.50±13.10 y; from Turkey	Measured by lateral radiograph Upright position – LE: relaxed standing Range: L1 SE–SP	LBP: nonspecific LBP HC: no LBP ever	Spondylolisthesis, inflammatory, infectious, malignant, metabolic disease of spine, marked scoliosis, pregnancy, previous spine surgery	4/9
Moon et al. 2001 [32]	Case-control	N LBP(M:F)=10(3:7), mean age=34.3±9.84 y; N HC(M:F)=10(5:5), mean age=26.6±3.57 y; from Korea	Measured by lateral radiograph Upright position – UE: forearm on firm support Range: L1 SE–L5 SE	LBP: outpatients, DH diagnosed by CT HC: no LBP>12 mo	Neurologic symptom, foot deformity, previous spine surgery, scoliosis	5/9
Korovessis et al. 2002 [30]	Prospective Case-control	Only male subjects, N LBP=100, mean age=46±15 y; N HC=100, mean age=49±18 y; from Greece	Measured by lateral radiograph Upright position – UE: grab bars in front Range: T12 IE–SP	Volunteers LBP: LBP duration<6 mo HC: no pain at inquiry point	DH verified in CT, previous spine or hip surgery, spondylolysis, spondylolisthesis, traumatic deformity, scoliosis, congenital deformity, limb leg discrepancy, complete interverterbral space collapse	5/9
Barrey et al. 2007 [21]	Retrospective Case-control	N LBP(M:F)=85(36:49), mean age=49±12 y; N HC(M:F)=160(74:86), mean age=27±8 y; from France	Measured by lateral radiograph Upright position – LE: knee extension – UE: hands on bars in front Range: IV–SP	LBP: scheduled for lumbar surgery for DH, DDD, or DSPL HC: without symptom of spinal disease (from previous study of same institute)	previous spine surgery, trauma or tumor involving spine, scoliosis, coxofemoral pathology, isthmic lysis	5/9
Abbas et al. 2010 [27]	Retrospective Case-control	N LBP(M:F)=67(30:37), mean age=66±10 y; N HC(M:F)=100(51:49) , mean age=63±13 y, from Israel	Measured by CT Supine position – LE: straight Range: L3 SE–SP	LBP: degenerative LSS diagnosed by claudication and small dural sac HC: no possible LSS related symptoms check by interview	Developmental stenosis, facture, tumor, Paget disease, iatrogenic stenosis	6/9
Endo et al. 2010 [28]	Retrospective Case-control	N LBP(M:F)=61(38:23), mean age=32.7, N HC(M:F)=60(39:21), mean age=32.7, from Japan	Measured by lateral radiograph Upright position – LE: relaxed stable standing – UE: hands clasped on opposite clavicle Range: L1 SE–SP	LBP: scheduled for simple herniectomy of L4–L5, L5–S1 DH HC: no DH-related symptoms		5/9

(*Continued*)

Table 1
(*Continued*)

Study	Study design	Study population	Lumbar lordosis	LBP or HC definition	Excluded from LBP	Risk of bias
Liu et al. 2015 [23]	Prospective for HC, retrospective for LBP Case-control	N LBP(M:F)=52(36:16), mean age=36.40±11.32 y; N HC(M:F)=61(25:36), mean age=62.28±10.70 y; from China	Measured by lateral radiograph Upright position Range: L1 SE–SP	LBP: scheduled for surgery for L4–L5 DSPL, LSS HC: asymptomatic volunteers	Trauma, tumor, severe osteoarthritis of lower extremity, previous spine surgery	5/9
Yang et al. 2014 [34]	Prospective Case-control	N LBP(M:F)=45(26:19), mean age=36.5±7.4 y; N HC(M:F)=115(71:44), mean age=36.7±7.0 y; from China	Measured by lateral radiograph Upright position – LE: knee extension – UE: hands placed on support Range: L1 SE–SP	LBP: symptomatic single-level DDD or DH HC: no LBP>5 y	Previous spine surgery, spinal deformity such as scoliosis, isthmic spondylolisthesis, irregular end plate, transitional vertebra, trauma or tumor of spine, lower extremity arthropathy	5/9
Nguyen et al. 2016 [26]	Prospective Case-control	N LBP(M:F)=7(5:2), mean age=35.14±8.97 y, N HC(M:F)=10(5:5), mean age=25.22±3.83 y, from USA	Measured by MRI Upright position LE: seated position Range: L1 SE–L5 IE	LBP: complaint of either LBP or radiculopathy HC: asymptomatic volunteers	Spinal deformity, underlying pathology, prior spinal injury or surgery	4/9

(M:F), (number of male subjects:number of female subjects); BL, the line that bisects the intervertebral disc space between the two vertebrae; CT, computed tomography; DDD, degenerative disc disease; DH, disc herniation; DSPL, degenerative spondylolisthesis; HC, healthy control; IE, inferior end plate; IV, the most inclined vertebra; LBP, low back pain; LE, lower extremity; LSS, lumbar spinal stenosis; MRI, magnetic resonance imaging; N, number of subjects; SE, superior end plate; SP, sacral plate; UE, upper extremity.

Definition of low back pain and healthy control group

The definition of patients with LBP and HCs varied across studies. Seven studies defined the LBP group as patients with specific spinal disease entities (disc herniation [21,28,32,34], degenerative disc disease [21,22,34], degenerative spondylolisthesis [21–23], lumbar spinal stenosis [23,27], and degenerative scoliosis [22]). Among these, three studies addressed patients scheduled for surgery [21,23,28], and the remaining had no specific description about the treatment sought by the patients. The remaining six studies defined the patient group as having nonspecific LBP. Four studies had limitations on the duration of symptoms; one had a maximum limit of 6 months [30], and three had minimum limits of 6 weeks [24,29] and 2 months [31]. The other two [26,33] had no detailed conditions as to the definition of LBP.

In terms of the definition of the HC group, seven studies [21,23,26–28,30,31] recruited persons without any relevant back-related symptoms at the time of study conduction. The remaining six studies set specific symptom-free duration limitations. The HC group was required to have been without LBP for at least 6 months in two studies [22,29], for 12 months in one study [32], and for 5 years in another [34]. The two remaining studies recruited only those who had never experienced LBP [24,33].

Measurement method of the lumbar lordotic angle

Most studies measured the LLA in an upright position, except for one study that measured it in the supine position [27]. All but two studies used lateral radiographs, except for one that used magnetic resonance imaging [26] and another that used computed tomography [27]. All used the Cobb method to assess the LLA, although the vertebral levels used for the measurement differed among studies. The anatomical structure most frequently used to signify the superior border of the LLC was the upper end plate of L1 (nine studies), followed by the inferior end plate of T12 (two studies) [30,31]. The superior end plate of the most inclined vertebra [21] and L3 [27] were each used in one study. To signify the inferior border of the LLC, the sacral plate (11 studies) was most frequently used, whereas the superior [32] and inferior [26] end plates of L5 were each used once.

Risk of bias

The susceptibility to bias varied among studies (Table 1, Supplementary Table S1). Two were of moderate quality [22,27], and the rest were of low quality. The inter-rater reliability showed an average measure intraclass correlation coefficient (95% CI) of 0.650 (−0.208, 0.895) ($F(12, 12)=2.733$, $p=.047$).

Lumbar lordotic angle in the low back pain and healthy control groups

The mean LLAs, SDs, and number of subjects in both the LBP and the HC groups are presented with the SMD between

Table 2
Mean lumbar lordotic angles and standard deviations of HC group and LBP group in the included studies

	Lumbar lordotic angle								
	HC group			LBP group					
Study or subgroup of study	Mean	SD	N	Mean	SD	N	SMD	Variance	95% CI
Jackson and McManus 1994 [29]	60.9	12.00	100	56.3	11.50	100	–0.391	0.020	[–0.671, –0.112]
Wood et al. 1996 [24] (p=.190)	58.8		50	55.7		50	–0.264	0.040	[–0.658, 0.130]
Jackson et al. 1998 [22]	62.1	10.80	50	59.28	12.88	110	–0.230	0.029	[–0.565, 0.105]
Degenerative disc disease				56.5	12.20	50	–0.486	0.041	[–0.884, –0.088]
L5–S1 isthmic spondylolisthesis				66.4	12.10	30	0.381	0.054	[–0.076, 0.837]
Scoliosis				56.8	12.01	30	–0.470	0.055	[–0.929, –0.012]
Korovessis et al. 1999 [31]	69.0	17.00	120	63.0	18.00	120	–0.520	0.103	[–1.150, 0.110]
Age 20–29 y	58.0	8.00	20	53.0	11.00	20	–0.175	0.100	[–0.796, 0.446]
Age 30–39 y	59.0	21.00	20	56.0	12.00	20	–0.997	0.112	[–1.654, –0.339]
Age 40–49 y	61.0	13.00	20	49.0	11.00	20	–1.325	0.122	[–2.010, –0.641]
Age 50–59 y	72.0	10.00	20	60.0	8.00	20	–0.894	0.110	[–1.543, –0.244]
Age 60–69 y	67.0	20.00	20	50.0	18.00	20	–0.499	0.103	[–1.128, 0.130]
Age 70–79 y	57.0	17.00	20	49.0	15.00	20	–0.343	0.017	[–0.598, –0.088]
Tuzun et al. 1999 [33]	46.0	13.90	50	44.95	12.33	100	–0.272	0.040	[–0.665, 0.122]
Acute LBP				42.7	10.10	50	–0.082	0.030	[–0.421, 0.258]
Chronic LBP				47.2	12.70	50	0.090	0.040	[–0.302, 0.482]
Moon et al. 2001 [32]	37.5	6.26	10	30.7	8.22	10	–0.931	0.222	[–1.853, –0.008]
Korovessis et al. 2002 [30]	52.0	13.00	100	49.0	14.00	100	–0.222	0.020	[–0.500, 0.056]
Barrey et al. 2007 [21]	61.0	9.70	160	52.16	13.04	85	–0.806	0.019	[–1.078, –0.533]
Degenerative disc disease				48.8	12.50	32	–1.193	0.042	[–1.593, –0.793]
Disc herniation				48.8	11.90	25	–1.217	0.051	[–1.658, –0.776]
Degenerative spondylolisthesis				59.0	11.90	28	–0.199	0.042	[–0.602, 0.204]
Abbas et al. 2010 [27]	45.20	7.00	100	42.8	7.00	67	–0.343	0.025	[–0.654, –0.031]
Endo et al. 2010 [28]	49.00	10.00	60	36.7	14.50	61	–0.986	0.037	[–1.363, –0.609]
Liu et al. 2015 [23]	42.53	7.86	52	36.01	12.92	61	–0.599	0.037	[–0.977, –0.221]
Degenerative spondylolisthesis				44.93	8.63	32	0.294	0.051	[–0.148, 0.737]
Spinal stenosis				26.17	9.18	29	–1.959	0.077	[–2.504, –1.414]
Yang et al. 2014 [34]	50.17	10.83	115	37.7	13.80	45	–1.063	0.034	[–1.427, –0.699]
No LBP	53.0	9.60	80				–1.356	0.042	[–1.758, –0.954]
No LBP and no disc herniation	43.7	10.70	35				–0.478	0.052	[–0.926, –0.030]
Nguyen et al. 2016 [26]	50.2	10.5	10	40.9	13.2	7	–0.798	0.262	[–1.800, 0.205]

CI, confidence interval; HC, healthy control; LBP, low back pain; N, number of subjects; SD, standard deviation; SMD, standardized mean difference.

the two groups and the pooled variance in Table 2. A negative SMD indicates that the LBP group has a smaller LLA than the HC group. The SMD varied from −1.96 to −0.08. In nine studies, the LBP group showed a reduced LLA compared with the HC group, with statistical significance [21–23,27–29,31,32,34]. The overall SMD ranged from –0.91 to –0.40 with considerable heterogeneity (Fig. 2, I^2=83.7%, p<.001).

Subsequent meta-regression and subgroup analyses were performed to investigate the source of heterogeneity. In the meta-regression analysis, the factors of age, disease entity, and pain severity were shown to have significantly influenced the degree of heterogeneity (Supplementary Table S1–S3). However, the chronicity of LBP and gender ratio were not shown to be significant factors in the meta-regression analysis.

In the subgroup analysis, the five studies that compared the HCs with the group with LBP and disc pathology (Fig. 3, I^2=45.7%, p=.118), which included disc herniation [28,32], disc degeneration [22], or both [21,34], showed sufficient homogeneity to deduce a pooled estimate, whereas the studies involving the group with LBP and lumbar spinal stenosis [23,27] showed considerable heterogeneity (I^2=96.1%, p<.001). Six age-matched studies [22,24,27,29–31] showed limited heterogeneity as well (Fig. 4, I^2=0%, p=.916). However, we were unable to find any subgroup categorized by the severity of LBP that was sufficiently homogenous to generate a pooled effect size. The pooled estimate SMD (95% CI) was –0.94 (–1.19, –0.69) in the disc pathology studies and –0.33 (–0.46, –0.21) in the age-matched studies.

Discussion

This review was conducted to investigate whether and how the LLC of patients with LBP might differ from that of HCs. A systematic search was performed and a meta-analysis was conducted. A total of 13 studies compared the LLA between subjects with and subjects without LBP. A majority showed that the LLA was significantly smaller in subjects with LBP. In the subgroup analysis, both the gender of the participants and the severity and chronicity of LBP failed to elucidate the

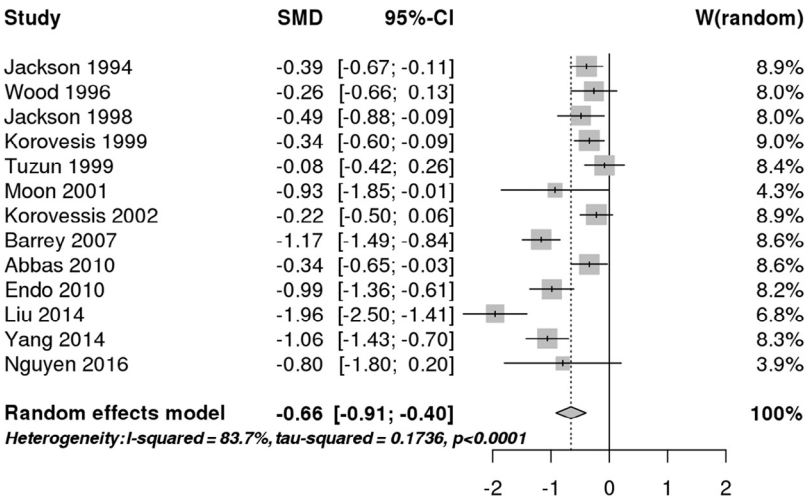

Fig. 2. Difference in lumbar lordotic angle between those with and those without LBP. Standardized mean difference, 95% confidence interval, forest plot, and weight of individual studies included in the meta-analysis. Negative values indicate that the LBP group has smaller angle than the control group. SMD, standardized mean difference; CI, confidence interval; W, weight.

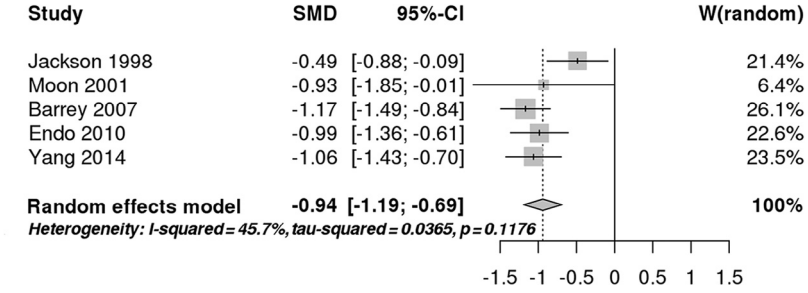

Fig. 3. Difference in lumbar lordotic angle between controls and patients with LBP and disc herniation or disc degeneration. Standardized mean difference, 95% confidence interval, forest plot, and weight of individual studies included in the subgroup analysis on studies that restricted the LBP group to patients with disc pathology. Negative values indicate that the LBP group has smaller angle than the control group. SMD, standardized mean difference; CI, confidence interval; W, weight.

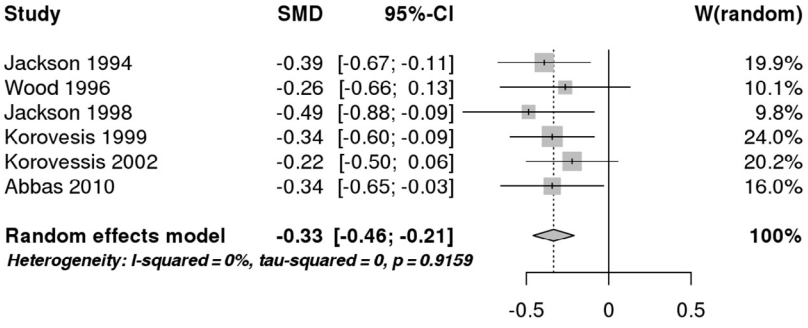

Fig. 4. Difference in lumbar lordotic angle between patients with LBP and age-matched controls. Standardized mean difference, 95% confidence interval, forest plot, and weight of individual studies included in the subgroup analysis on studies that matched the age of the LBP group and the control group. Negative values indicate that the LBP group has smaller angle than the control group. SMD, standardized mean difference; CI, confidence interval; W, weight.

source of the heterogeneity among studies. The studies that used patients with disc pathology as the LBP group, as well as the age-matched studies, showed sufficient homogeneity to deduce a pooled estimate. In both cases, patients with LBP were shown to have a significantly attenuated LLC compared with that of the HCs.

Low back pain versus lumbar lordotic curve

The fact that 9 out of 13 studies reported smaller LLA in patients with LBP than in HCs, with statistical significance, is worthy of note. Although statistical significances were not achieved, the remaining four studies also reported

decreased LLA in the LBP group. Generally, if studies included in a meta-analysis had investigated the same, so-called homogeneous, population, the difference in results would solely be due to sampling error. However, this is rarely the case and there is typically natural heterogeneity among studies [35]. The determination of a homogeneous subgroup is necessary to draw a pooled estimate [36]. Although we set strict criteria to guarantee qualitative homogeneity, we failed to achieve statistical homogeneity. Although the heterogeneity among the included studies precludes general speculations as to the relationship between LBP and LLC, this result implies a substantial relationship between attenuated LLC and LBP.

This association is probably mediated by the underlying spinal disease because patients with LBP have secondary causes of back pain such as disc degeneration, spinal stenosis, and disc herniation, which can cause and contribute to LBP than attenuation of LLC only. To scrutinize this issue with currently available studies, an additional subgroup analysis was performed including the studies that did not specify the disease entity of the LBP group, which showed less difference in LLA between patients with LBP and HCs [24,26,29–31,33]. However, even in this analysis, the pooled estimate SMD (95% CI) was –0.29 (–0.42, –0.15) with limited heterogeneity (I2=0%, p=.647), which implies that the LLA is smaller even in patients with nonspecific LBP. This might be because these studies merely did not identify the patients' condition that manifest LBP and most of the patients would have had some kind of spinal disease.

Although a significant association between attenuated lumbar lordosis and LBP was evidenced by the results of this meta-analysis, no causal relationships were able to be surmised based on the data from observational studies. Fortunately, there was one study [25] detected in this systematic search that investigated the relationship between LLC and LBP in a longitudinal design. This study investigated the personal characteristics of 403 health-care workers that were predictive of future incidence of back problems. In accordance with our results, reduced lumbar lordosis was found to be one of the major risk factors predictive of "serious" LBP, defined as LBP requiring medical attention or time off work. They speculated that lumbar lordosis played a shock-absorbing role in the prevention of LBP. Depending on their results, there is a high likelihood that the substantial association between smaller LLC and LBP found in our results would be a cause and effect relationship, where the former works as a cause. However, there was only one longitudinal study, and in the study, the LLC was assessed by clinical measures, allowing for the possibility that the surface concavity of the lumbar spine might have been overestimated by the gluteal muscles [37] that act as spinal stabilizers via the thoracolumbar fascia [38]. The fact that the female subjects outnumbered the male subjects (371:32) presented another potential bias. Further longitudinal studies that use radiological measures to assess LLC are necessary to reveal the causal relationship between lumbar spinal alignment and LBP.

Factors that influence the association between low back pain and lumbar lordotic curvature

Five factors were considered clinically significant determinants of LLC, namely the age and gender of the participants, the LBP severity and chronicity, and the spinal disease entity. Lumbar lordotic curvature decreases with age [39], and factors that would affect the sagittal balance were shown to vary according to gender [40]. The severity of pain was associated to the extent of postural coping. As with the chronicity of LBP, a large number of patients with acute LBP were shown to benefit from extension mobilization [41], whereas many with chronic LBP and claudication benefitted from a flexed posture [42]. Clearly, spinal disease entity must be included as a possible determinant of the degree of LLC because some spinal disease is closely related to LLC [43]. However, we failed to reveal whether gender, chronicity, and severity of LBP had any significant association with LLC alteration because of a lack of information pertaining to these factors in the included studies. For example, in terms of gender, none of the included studies reported the LLA of subgroups divided by gender, and whether they had LBP.

The subgroup sorted by age and spinal pathology showed sufficient homogeneity to make a conclusion as to whether the LLC would differ between patients with LBP and HCs in the corresponding subgroup. Specifically, patients with LBP showed attenuated LLC compared with healthy people, when both were of similar age or in cases of disc pathology (disc herniation or disc degeneration). This could be revealed because the included studies provided information on these factors. Most studies presented age data for both the LBP group and the HC group, and many others limited the LBP group to those with a specific spinal pathology. Nonetheless, these results imply that age and disc pathology strongly influence the relationship between LLC and LBP, and demonstrate the predominance of smaller LLA in patients with LBP.

Lumbar lordosis and disc pathology

The homogeneity of the results among studies about patients with disc pathology appears to be due to the innate characteristics of the degenerative process of the spine. Constructional deformation of the disc is the first finding in the degenerative cascade of the lumbar spine [2]. Four out of five studies included in the disc pathology group defined the LBP group as those subjects with symptomatic disc herniation or one- or two-level disc degeneration. The remaining study had no specific description as to the extent of disc degeneration; however, the average age of the patients was less than 40 years, implying less extensive levels of disc degeneration [22]. Thus, patients with disc pathology would be relatively homogeneous because of the early stage of the degenerative process. On the other hand, as spinal degeneration progresses into more advanced or even end stages, various degenerative conditions of the spine can coexist. For example, patients with spinal stenosis might present with both degenerative disc disease and

spondylolisthesis with a diversity of levels of severity, which would render a group of patients with spinal stenosis heterogeneous by nature. This may be why the disc pathology subgroup was homogenous, whereas the lumbar spinal stenosis subgroup was not.

The angulation of lumbosacral intervertebral discs forms about 80% of the LLC [44]. The decrement of LLC is mostly due to the wedging of the intervertebral discs in the absence of vertebral fractures [13]. Disc height decreases as disc degeneration progresses, which is closely associated with the angle of lordosis [45]. Thus, the degenerative process of the lumbar intervertebral discs can eventually cause attenuated LLC. Loss of lumbar lordosis is closely related to anterior sagittal imbalance [13], which increases the stress and loading on the intervertebral discs. Prolonged loading on the intervertebral discs induces the cellular cascade that is known to play a role in disc degeneration [46,47]. In sum, the change in sagittal alignment induced by disc pathology affects the discs in an unfavorable fashion.

Lumbar lordosis and age

Lumbar lordotic curvature naturally decreases with age. Takeda et al. investigated the longitudinal changes in the sagittal alignment of healthy elderly subjects. Subjects aged 50 years or more who had neither a history of spinal pathology requiring hospitalization nor systemic or spinal disease requiring repetitive medical consultations were retrospectively selected from a community-based cohort. The absence of vertebral fracture was confirmed by both history and radiography. The 53 subjects who met the inclusion criteria showed a 7.7° decrement of lumbar lordosis, defined as the Cobb angle between the superior end plate of L1 and the inferior end plate of L5, during the 10-year follow-up, with statistical significance ($p<.001$) [13]. In most of the studies included in the current systematic review, the controls were younger than the patients with LBP. Thus, the smaller LLA in patients with LBP might be attributed to the age difference between the LBP group and the HC group. Clearly, age-matched design is necessary to rigorously explore the relationship between LBP and LLC. Nonetheless, as revealed in the present meta-analysis, patients with LBP showed decreased LLC compared with HCs even after controlling for the influence of age.

The limited heterogeneity among studies that investigated patients with disc pathology can also be explained in terms of age. Lumbar lordotic curvature is determined by the morphology of vertebral bodies, end plates, and intervertebral discs, of which structures and biomechanical properties vary as a function of age [48]. Therefore, positively impacting age-related spinal degeneration might overcome all of the other confounding factors. The LBP groups in the five studies incorporating the disc pathology subgroup were relatively young (less than 40 years in four [22,28,32,34], and 45.1 years in one [21]). Thus, the structural alteration caused by spinal degeneration would not typically be advanced in this subgroup, and possible sources of heterogeneity might have been controlled.

Implications of lumbar lordotic curvature in therapeutic exercises for patients with low back pain

Loss of LLC shown in patients with LBP is frequently interpreted as a coping strategy to alleviate pain, and a few assert that reduced lordosis is the cause of LBP. This is because trunk extension frequently aggravates LBP in some patients, and hyperlordosis is related to some spinal diseases (eg, isthmic spondylolisthesis) [49]. It is well known that patients with spinal stenosis relieve claudication by sitting or squatting. Furthermore, flexibility training is a major component of therapeutic exercise in general. Thus, exercises emphasizing spinal flexion or back muscle stretching, such as Williams exercise, have been widely incorporated in the therapeutic exercise regimens of patients with LBP.

Achieving a proper lordotic angle in spinal fusion surgeries is a key component of a successful outcome [50], which implies that adequate LLC is necessary for a healthy spine. After the complications of iatrogenic flatback became an issue, many clinicians tried to figure out the optimal lordosis that should be engendered by surgery. Because the lumbar spine is motile and variable, an innately fixed parameter of the individual, namely pelvic incidence, gained recognition as the reference for the optimal range of LLC [51]. However, lumbar alignment can be altered by voluntary motions, which makes it a more suitable target of interest for therapeutic exercise in the treatment of LBP. Future studies of systematic review with or without meta-analysis on other radiological parameters such as pelvic incidence, C7 plumb line, sacral slope, and so on could help enhance our understanding of the spinal sagittal balance as a whole. In the current systematic review, all studies reported attenuated LLC in patients with LBP compared with HCs. Many LBP exercises currently used in the clinical field that emphasize flexion stretching seem contradictory to results of this review.

The smaller LLC observed in the patient group, along with LBP, might be the result of a spinal pathology, although loss of lordosis should still be considered a valid target of treatment. Studies on the outcome of lumbar surgeries revealed that the restoration of sagittal balance is directly related to improvements in both functionality and pain [52]. Moreover, anterior sagittal imbalance is associated with increased postural stresses and loads on the intervertebral discs [53], which leads to sustained compressive loading, which initiates harmful changes at the cellular and structural levels [54]. Regardless of whether loss of LLC is a result of normal aging or spinal pathology, it would appear to be helpful to correct the decreased LLC for treating or preventing future recurrence of LBP.

Limitations

There were several limitations in this meta-analysis. There was substantial heterogeneity among studies not explained by anticipated moderator factors. We preselected various candidate factors that might influence the LLC. However, in the

meta-regression analysis, only age, disease entity, and pain severity were shown to be significant explanatory factors of heterogeneity. The rate of heterogeneity explained by these factors was approximately 65%.

A majority of studies showed low quality in the assessment of risk of bias, and most studies did not control for the factors that might affect LLC. Furthermore, whether the LLC was measured by a blinded evaluator was not described, and the inter-rater reliability was not reported, in most studies. Nonetheless, observational studies tend to be relatively free from intended bias compared with interventional studies, where low quality undermines the reliability of the study results.

Although spondylolisthesis accounts for a significant portion of patients with LBP, this disease was excluded in the meta-analysis because of the fact that it can be a compensatory change to maintain sagittal balance without altering LLA while accommodating the pelvic orientation [55]. Many studies also deliberately excluded spondylolisthesis, making it difficult to include spondylolisthesis in the meta-analysis.

Conclusion

In our analysis of a total of 796 patients with LBP and 927 HCs from 13 published reports, patients with LBP tended to have attenuated LLC compared with HCs. Subgroup analyses revealed that studies including patients with LBP because of disc pathology and patients with LBP compared with age-matched controls clearly demonstrated that patients with LBP had decreased LLC compared with that of HCs.

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Supplementary material

Supplementary material related to this article can be found at http://dx.doi.org/10.1016/j.spinee.2017.04.034.

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