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Segmental Contributions to Lumbar Lordosis: A Computed Tomography Study

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ABSTRACT

Background: The aim of this study was to determine the contribution of individual vertebral body lordosis to lumbar lordosis and establish the relationship of vertebral body lordosis to the pelvic incidence (PI).

Methods: One-hundred and two computed tomography (CT) scans on patients free of radiographic disease were measured for PI and segmental lordosis of both bone and disc from L1 to sacrum. Correlative analysis and analysis of variance (ANOVA) were used to identify contribution from bone and disc to lordosis.

Results: The mean total bony lordosis was 10.8° (SD 11.5°), mean total disc lordosis was 36.3° (SD 9.9°), and mean combined lordosis was 47.1° (SD 10.0°). The mean PI of the entire cohort was 49.2° (SD 9.3°). One-way ANOVA demonstrated a significant difference between the PI strata in total bony lordosis values with a mean difference of 14.0° between low and high PI cohorts ($P < .001$) and also mid- and high PI cohorts of 9.9° ($P = .008$). Overall, distal lordosis represented 80.8% of the total lordosis. In the proximal lumbar segments, the mean contribution from bone was -4.0° (SD 6.8°) and the mean contribution from disc was 13.6° (SD 6.0°). In the distal, the mean contribution from bone was 14.7° (SD 6.5°) and from disc, 22.7° (SD 6.2°).

Conclusions: The contribution to lordosis from the vertebral bodies is greater in the proximal lumbar spine with increasing PI. With low PI, the proximal vertebral bodies demonstrate reduced contribution to lordosis and in some instances are kyphotic. Future research efforts should place greater emphasis on providing segmental rather than just global analysis of alignment.

Clinical Relevance: Restoration of lumbar spine lordosis should take into account the variation in segmental lordosis contributions as it relates to PI.

Lumbar Spine

Keywords: lumbar lordosis, segmental lordosis, pelvic incidence

INTRODUCTION

Patient-specific sagittal alignment of the spine is well-established as a surgical goal in reconstructive procedures on the spinal column. Numerous studies have reported the clinical significance of imbalance and the importance of restoring balance during surgery with failure to do so compromising the patients' clinical outcome resulting in poorer health-related quality of life scores, increased pain, and higher rates of revision surgery.^{1–5}

The pelvic incidence (PI), first described over 30 years ago, is the corner stone of surgical planning.⁶ The ideal individual lumbar lordosis (LL) can be predicted from the PI, a fixed anatomic value that does not change once an individual reaches skeletal maturity. When the PI and LL mismatch is greater than 10° significant deterioration in health-related quality of life (HRQOL) scores are seen, the

potential for adjacent segment disease increased and need for revision surgery is greater. PI=LL has formed the basis for initial surgical planning of lordosis recreation.^{5,7,8} More recently, with analysis of large data sets, the ability to predict idealized LL for an individual has been enhanced with more precise calculations being offered.^{9,10} However, part of the complexity in planning sagittal realignment is the reliance on normative data from data sets using imaging taken with the subject standing. It is increasingly acknowledged that other functional positions including sitting and lying should be considered when considering what the ideal alignment is for an individual.

An important step in the evolution of surgical planning has been the understanding of segmental contributions throughout the lumbar spine and how these relate to the PI. Anwar et al¹¹ demonstrated that a majority of LL arises from the caudad 2 (L4/5

and L5/S1) motion segments but that the contribution from the more cephalad segments (L1/2, L2/3, and L3/4) increased with increasing PI.¹¹ Similarly, Pesenti et al¹² detailed that the lower 2 motion segments contribute over 60% of LL but noted that PI only correlated with the LL in the proximal lumbar spine. The findings of Anwar et al¹¹ and Pesenti et al¹² underpin the development of the Global Alignment and Proportion Score, which indicated the need to ensure that recreation of LL is achieved in the correct region of the spine.^{9,11,12}

Previous analysis of segmental contributions to LL have used plain radiographs using cohorts of patients attending a spinal deformity clinic and asymptomatic volunteers. Assessment using advanced imaging modalities, such as computed tomography (CT), offers advantages over plain radiography including optimum imaging of the mid sagittal plane of the vertebral body, and the ability to accurately identify transitional anatomy and pathologic processes. The aim of this study, utilizing CT imaging, was to define the contribution of the individual vertebral bodies and discs to LL, define the contribution to proximal and distal lordosis, and relate these contributions to the PI.

METHODS

Local ethical approval was obtained for this study (Health and Disability Ethics Committee; 18/CEN/8).

CT images obtained for major trauma assessment were obtained from the hospital radiology server over a 1-year period, July 2017–August 2018. All scans were taken with the patient supine. Scans were reviewed to identify those that included imaging of the entire spinal column and pelvis.

In an attempt to minimize pathologic spines from analysis, scans were then excluded from analysis if there was any destructive pathology (trauma, tumor, infection) or previous surgery (spinal fusion, spinal instrumentation, hip arthroplasty) that precluded measurement of sacropelvic parameters or segmental spinal values. Scans were also excluded from analysis if there was evidence of degenerative spinal column disease including the presence of osteophyte, endplate sclerosis, or vacuum phenomena of the disc, and if there was antero- or retrolisthesis or evidence of spondylolysis. All scans were reviewed to determine the presence of 7 cervical, 12 thoracic, and 5 lumbar vertebrae and patients with abnormal numbering



Figure 1. Technique for measuring the pelvic incidence (PI) and segmental disc angles.

excluded. Finally, patients with Castellvi Type III and IV transitional lumbosacral vertebrae were excluded.¹³

Basic demographic data including age and gender were recorded. All images were analyzed on the IntelliSpace PACS 4.4 Enterprise (Koninklijke Phillips, NV). PI was measured as well described identifying the center of the femoral heads on the respective sagittal slices, then identifying the bicoxofemoral axis in the midsagittal plane (Figure 1).⁶ In the midsagittal plane, the endplates were identified of each vertebral body from L1 to L5 and the sacrum allowing measurement of the vertebral body and disc angles (Figures 1 and 2). A negative value indicated a kyphotic value whilst a positive value was lordotic.

Segmental values were considered in isolation but also as total vertebral body values, total disc values, and total combined. Lordosis was also assessed according to location, either proximal (measures from the superior endplate of L1 to the superior endplate of L4) or distal (all measures from the superior endplate of L4 to the endplate of S1).

The entire cohort was analyzed as a whole and then subgroup analysis performed based on stratification of the PI into low-, mid-, and high-value groups as has previously been done.¹²



Figure 2. Technique for measuring the pelvic incidence (PI) and segmental vertebral body angles.

Statistics

All data were recorded and stored on an Excel spreadsheet. Basic statistical results are reported as mean (and SD). As required, a 1-way analysis of variance (ANOVA) and Pearson correlation analysis was performed using the Jamovi statistics package. A posthoc Tukey test was used for intergroup comparison as required. For all tests, statistical significance was set at $P < .05$.

RESULTS

Scans of 102 patients were included in the analysis. The mean age of the cohort was 37.4 years (SD 14.4; range 17–68 years), with 67 males (66%). The mean total bony lordosis was 10.8° (11.5°),

mean total disc lordosis was 36.3° (9.9°), and mean combined lordosis was 47.1° (10.0°).

The mean PI of the entire cohort was 49.2° (9.3°). When the PI was stratified into low-, mid-, and high-value subgroups: 24 had a $PI \leq 45^\circ$, 34 a $PI 46^\circ\text{--}60^\circ$, and 9 a $PI > 60^\circ$. There was no significant difference in the mean age between PI strata ($P = .267$) nor any significant correlation between age and PI ($r = .069$; $P = .488$).

Combined Lordosis

The mean total lordosis for low-, mid-, and high PI strata was 40.4° (8.5°), 50.0° (9.2°), and 54.3° (5.4°), respectively. One-way ANOVA revealed significant differences between low and mid-PI strata (9.6° , $P < .001$), between low and high PI strata (13.9° , $P < .001$) but not between mid- and high PI strata (4.3° , $P = .223$).

Contribution From Vertebral Bodies

Table 1 shows the results from the individual bony measures across the entire cohort but also by stratification of PI. One-way ANOVA demonstrated a significant difference between the PI strata in total bony lordosis values with a mean difference of 14.0° between low and high PI cohorts ($P < .001$) and also mid- and high PI cohorts of 9.9° ($P = .008$). There was no significant difference between low and mid-PI (4.1° ; $P = .184$).

Contribution From Discs

Table 2 shows the results from the individual disc measurements across the entire cohort and by stratification of PI. One-way ANOVA showed a significant difference in the total discal lordosis values with a mean difference of 5.5° between low and mid-PI cohorts ($P = .023$). There was no significant difference detected between low and high PI cohorts (0.04° ; $P = 1.0$) and mid- and high PI cohorts (5.6° ; $P = .134$).

Table 1. Mean (and SD) values are provided for the vertebral body lordosis at each level for the entire cohort and by stratification of pelvic incidence into low, mid, and high groups. *P* values provided are from the 1-way analysis of variance comparing values according to the stratification.

	L1	L2	L3	L4	L5	TBL
Complete	-4.5° (3.3°)	-1.3° (2.8°)	1.8° (2.5°)	4.5° (3.3°)	10.2° (4.4°)	10.7° (11.5°)
Low PI	-5.4° (3.3°)	-2° (2.7°)	0.9° (2.5°)	3.7° (3.4°)	9.6° (3.7°)	6.8° (10.6°)
Mid PI	-4.3° (3.5°)	-1.2° (2.9°)	1.8° (2.1°)	4.5° (3.1°)	10.1° (4.8°)	10.9° (11.1°)
High PI	-2.9° (2.4°)	0.3° (1.9°)	4.3° (2.8°)	6.6° (3.1°)	12.5° (4.1°)	20.8° (8.8°)
<i>P</i> value	.017	.006	.002	.023	.078	<.001

Table 2. Mean (and SD) values are provided for the disc lordosis at each level for the entire cohort and by stratification of pelvic incidence into low, mid, and high groups. *P* values provided are from the 1-way analysis of variance comparing values according to the stratification.

	L1/2	L2/3	L3/4	L4/5	L5/S1	TDL
Complete	3.6° (2.5°)	4.4° (2.5°)	5.5° (2.6°)	8.5° (2.7°)	14.2° (4.8°)	36.3° (9.9°)
Low PI	3.7° (2.3°)	4.1° (2.0°)	4.8° (2.5°)	7.4° (2.6°)	13.4° (4.8°)	33.5° (9.0°)
Mid PI	3.8° (2.7°)	4.8° (2.8°)	6.1° (2.6°)	9.3° (2.6°)	15.1° (5.0°)	39.1° (10.1°)
High PI	2.9° (2.5°)	3.7° (2.2°)	5.1° (2.4°)	8.4° (2.8°)	13.4° (4.3°)	33.5° (8.9°)
<i>P</i> value	.443	.230	.086	.011	.219	.022

Proximal and Distal Contributions

When the entire cohort was analyzed, the mean proximal lordosis was 9.6° (6.4°), and the mean distal lordosis was 37.5° (7.1°). Overall, distal lordosis represented 80.8% of the total lordosis. In the proximal lumbar segments, the mean contribution from bone was -4.0° (6.8°), and the mean contribution from disc was 13.6° (6.0°). In the distal, the mean contribution from bone was 14.7° (6.5°) and from disc, 22.7° (6.2°).

Considering the segmental contribution to lordosis from bone and disc in proximal and distal segments of the lumbar spine (Table 3), 1-way ANOVA showed significant differences in proximal bony lordosis between low and high PI strata ($P < .001$) and mid- and high PI strata ($P = .014$) but not between low and mid-PI ($P = .127$). In the proximal segments, 1-way ANOVA did not reveal any significant difference in the segmental disc measurements between strata. In the distal segments, there was a significant difference between the low and mid-PI strata ($P = .022$) but not among the others.

Pearson correlation demonstrated the relationship between proximal and distal lumbar bone and disc contributions to lordosis (Table 4). Significant correlation was seen between the PI and lordosis measurements from bone but not disc. Age was also tested with a weak positive correlation evident with lordosis from proximal ($r = .343$; $P < .001$) and distal disc measures ($r = .214$; $P = .031$) but not with

proximal ($r = .134$, $P = .179$) nor distal bone measures ($r = .125$; $P = .209$).

DISCUSSION

The aim of this study, using a series of CT images for analysis, was to define the contributions of the individual vertebral bodies and discs to LL in the supine position using a series of CT images for analysis. Although it was shown that the contribution to lordosis from the vertebral bodies increased from proximal to distal, we determined that the mean lordosis of the proximal vertebral bodies increased with increasing PI. The contribution to overall lordosis from the L1-3 vertebral bodies correlated with PI slightly more strongly than did the contribution from the L4-5 bodies.

It is clear, in conjunction with earlier findings by Anwar et al¹¹ and Pesenti et al,¹² that the higher the PI is, the more the proximal segments contribute to LL. Anwar et al¹¹ noted that the L1 and L2 vertebral bodies were actually kyphotic with mean angles of -0.56° and -0.35°, respectively. The results here were more marked with values of -4.5° and -1.3°—this difference may reflect the use of an alternate imaging modality for assessment. Pesenti et al¹² do not provide separate analysis of vertebral body and disc angles but report the segmental lordosis reflecting the combined contribution of bone and disc at each level. In contrast to their finding that PI did not correlate with distal lumbar segmental lordosis, this current study demonstrated that PI correlated with the vertebral body lordosis values in both proximal and distal regions of the lumbar spine.¹² This is a further key finding for surgical planning and suggests that the variation in proportional lordosis between the proximal and distal regions of the lumbar spine, at least in the standing position, is primarily influenced by the lordotic change in the disc space. Indeed, it is well described how lordosis changes between positions

Table 3. Mean (and SD) values are provided for the vertebral body and disc lordosis in proximal and distal segments of the lumbar spine for the entire cohort and by stratification of pelvic incidence into low, mid, and high groups. *P* values provided are from the 1-way analysis of variance comparing values according to the stratification.

	L1-3 Bone	L4-5 Bone	L1/2/3/4 Disc	L4/5/S1 Disc
Complete, °	-4.0 (6.8)	14.7 (6.5)	13.6 (6.0)	22.7 (6.2)
Low PI, °	-6.3 (6.2)	13.2 (5.9)	12.7 (5.2)	20.8 (5.9)
Mid PI, °	-3.7 (6.7)	14.6 (6.7)	14.7 (6.2)	24.4 (6.3)
High PI, °	1.7 (5.1)	19.1 (5.9)	11.6 (6.5)	21.9 (5.3)
<i>P</i> value	<.001	.013	.159	.034

Table 4. Results from the Pearson correlation matrix demonstrating relationship of pelvic incidence with the proximal and distal lumbar bone and disc lordosis measures.

	L1-3 Bone	L4-5 Bone	L1/2/3/4 Disc	L4/5/S1 Disc
Pearson <i>r</i>	.412	.328	.017	.126
95% confidence interval	0.236 to 0.561	0.142 to 0.491	-0.179 to 0.210	-0.070 to 0.313
<i>P</i> value	<.001	<.001	.869	.206

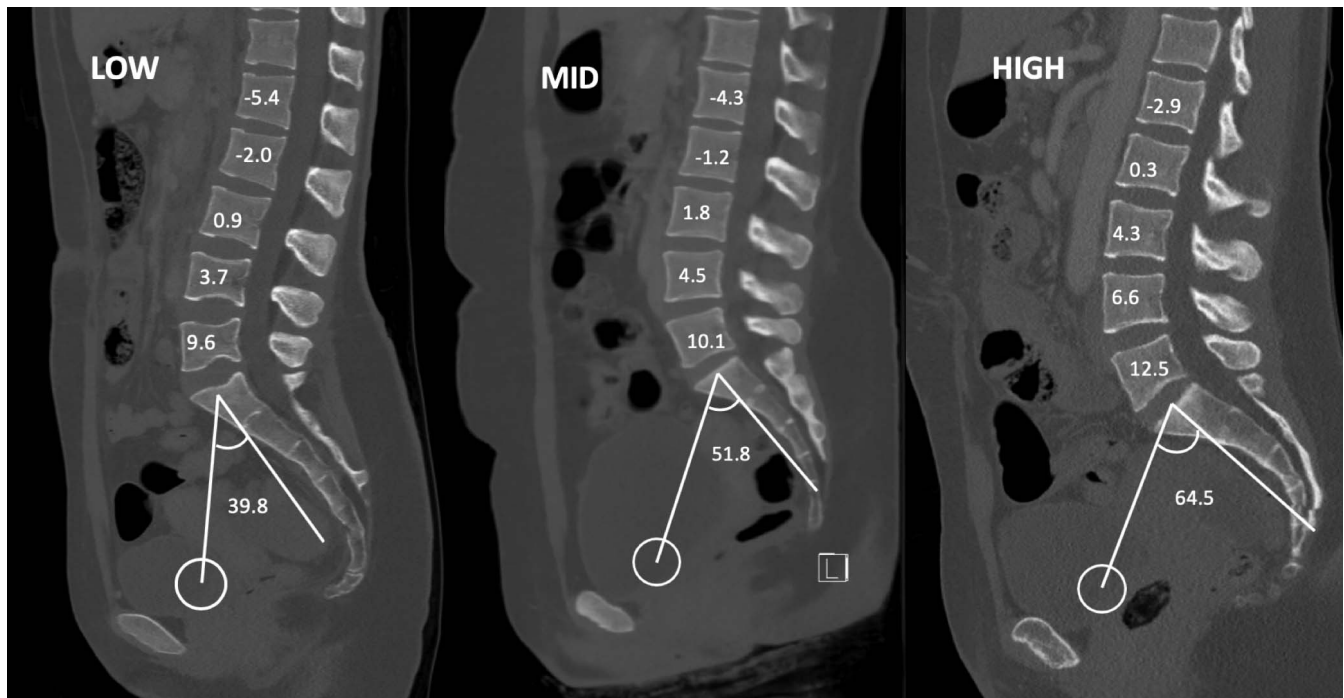
and one can anticipate that the disc angle would vary between standing and supine positions.¹⁴

In a study comparing the contribution to lordosis in humans and macaques, Been et al¹⁵ report kyphotic wedging in the proximal 2 vertebral bodies with mean values of -4° and -1° at L1 and L2, respectively. Similarly, Chen¹⁶ described kyphotic angulation at these levels in a population of Chinese males with mean values, in a neutral standing position, of -5.8° and -4.4° . Neither study provides an analysis of the vertebral body contribution to lordosis with consideration of the PI and how the measures may be related. Although Vialle et al¹⁷ analyzed the segmental contributions to lordosis from the lower thoracic spine to the sacrum, the measures do not isolate the vertebral body contributions.

Consideration of the contribution to lordosis by the vertebral bodies and discs as separate entities is important. The failure of earlier work to describe the contributions of both vertebral body and disc is

a key omission as knowing the separate contributions from both vertebral body and disc is important to allow an understanding of the ideal, or target, disc lordosis that should be restored at surgery.¹² Using interbody devices to correct segmental loss of alignment, particularly over multiple levels, could lead to over- or undercorrection if one is not aware of the kyphotic nature of the adjacent vertebral body.^{18,19} This underpins the need to achieve proportional spread of lordosis highlighted by increased failure when lordosis recreation is not proportional.^{8,9} Future work analyzing segmental contribution to global LL should consist of separate vertebral body and disc space measurements.

Limitations of this study include the use of imaging taken in a single position. Ideally, parameters would be measured in each of lying, sitting, and standing positions for the same individuals, but exposure to such radiation would be unethical for the purposes of obtaining normative data. However,

**Figure 3.** Mean vertebral body and pelvic incidence (PI) values for the low, mid, and high PI cohorts.

it is equally important to consider 3 functional alignments of the spine—erect, supine, and sitting postures—and this current study adds to the growing body of literature that examines the segmental contributions to global LL. Consideration of spinal alignment in each posture will likely be critical as understanding of optimum lordotic recreation evolves. To date, much research has focused on alignment of the spine in the erect position and attempts to recreate alignment based on this normative data are still met with considerably high failure rates.

We attempted to minimize inclusion of pathological spines based on the CT appearances—although this is not the ideal modality to assess degenerative disease, this is balanced against the ease of analysis using CT and also access to a large volume of whole spine imaging, which has other benefits including accurately determining vertebral body counts and detecting the presence of transitional anatomy. Similarly, we did not contact patients to ascertain the presence or absence of symptoms attributable to the spinal column, although we did not think the vertebral body measures would be significantly influenced by this given the exclusion criteria applied.

CONCLUSION

In summary, based on an analysis of CT scans in patients free of radiographic disease, it is evident that the vertebral body contributions to overall supine lordosis proportionally increase from proximal to distal, but the proximal contribution increases with increasing PI. Surgeons can take into account these findings during planning of patient-specific recreation of spinal alignment. Future efforts should consider reporting the contribution of the vertebral body and disc separately in addition to the segmental lordosis.

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