ANALYSIS OF LUMBOSACRAL LORDOSIS USING STANDING LATERAL RADIOGRAPHS THROUGH CURVE RECONSTRUCTION

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ABSTRACT

The consensus of the normal magnitude of lumbosacral curve has not been achieved. The Cobb's angle cannot depict the whole contour of this curve. For practical applications, a clearer image of these curves and their aging changes should be further investigated. This study aimed to provide a more consolidate concept of normal lumbosacral curves for clinician through a computerized reconstruction method.

Standing lateral radiographs of lumbosacral spine in 82 normal adults were used for reconstructing the sagittal lumbosacral curves. The geometric characteristics of these curves according to the gender and age groups were studied. Using standing lateral radiographs, reconstruction of the lumbosacral curves was performed through digitization, programming and computation. These curves and related parameters were normalized and averaged for analyzing the differences of gender and age.

The most anteriorward and horizontal vertebrae usually occurred on the L4 and L3 in any gender and age groups. The sacral inclination angle did not change obviously with the increasing ages. A tendency of L1 shifting backward was noted in the age groups of 40 to 60 and above 60 years old. The sagittal lumbosacral curves can be easily reconstructed by digitizing lateral radiographs. The aging changes of lumbosacral curves could be qualitatively described as the flattening of lower lumbar curve and the rearward inclination of upper lumbar curve. The changes occurred obviously above 40 years old. Although individual variations existed, the aging changes and the geometric characteristics such as the most anteriorward or horizontal vertebrae could be used as an important guideline during therapy or surgical correction.

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1. INTRODUCTION

Lumbar lordosis appears as the child begins to

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stand and later to walk. The lordosis will increase till adult. It develops as a secondary curve and enables the spinal column to transmit the weight of the trunk to the pelvis so that little muscle effort is needed to maintain the erect attitude[1,26]. Its contours could be changed by posture, degeneration, inflammation, trauma or surgery. Of them, the aging process plays the major role[10,23].

Although controversial, the magnitude of lumbosacral curves was related to the possible causes of lower back pain[6,9,12,25]. Furthermore, the impor-

tance of lumbosacral lordosis was never neglected especially in the field of spinal surgery. Loss of lordosis after instrumented spinal fusion often results in sagittal spinal balance and persistent back pain, so-called flat-back syndrome[14,16,22]. Many measures were thus taken to preserve the lumbar lordosis. Besides the techniques of rod bending, some authors claimed that the four-post spinal frames were more helpful for obtaining a satisfactory lumbosacral curves[11,19]. The preoperative standing curvatures were usually applied as a standard for correction.

However, the definition of normal lumbar curves was still ambiguous whether in conservative management or surgical correction. Many efforts were done to depict the profiles of the lumbosacral curves [4,8,13,17]. The individualized variations were one of the major reasons. Cobb's angle is the simplest way. A TRALL method was claimed to be more reliable because the posterior margin of vertebrae was used, which is more stable and not related to the aging[5]. However both methods described only the segmental angulation and cannot give us the images of the contours.

With the development of computer and digitized tablet, reconstruction of the whole lumbosacral curves became easy. Some authors already used these techniques for the reconstruction of spinal curves. Beck[3] used the lumbosacral hinge as the origin of the coordinate system and reconstructed the whole spinal curves by marking the geometric center of each vertebrae and equalizing the sagittal segmental distances. Although he reconstructed and analyzed the curves qualitatively, the ways of practical application is still lacking.

During[7] took three upper frontal vertices of L4, L5 and Sacrum to plot an imaged arc of lordosis in order to study the relationships between the lumbar spine and pelvis. He noted that the sacral inclination angle would be closely related to not only the radius of the imaged arc but also the center location of the curvature.

The above studies gave us much meaningful information. But for a spinal surgeon who often tried to make a satisfactory sagittal profile of lumbosacral curve for patients, the current knowledge is obviously not enough. Therefore, we intended to investigate the characteristics and evolution of normal lumbar curves by using the computed curve reconstruction through a geometric modeling. And the purpose of this study is to provide a more consolidate concept of normal lumbosacral curves and hopefully the spinal surgeon has more confidence when they try to reconstruct a lumbar curve.

2. MATERIALS AND METHODS

In the study, 82 normal adults (45 Male and 37 Female) without significant back pain were randomly

selected. The average age was 52 years old (ranged from 23 to 77 years).

For each subject, a set of standing posteroanterior and lateral X-rays was prepared. While taking the X-rays, the subjects were asked to have their arms elevated anteriorward of 30 degrees in a relax standing. A radiopaque ruler and a plumb line were used as the calibration markers. X-rays with the findings of spondylolisthesis, scoliosis or other deformities were excluded in this study. Only the lateral X-rays were used for analysis.

On each lateral radiograph, a senior resident marked 31 points which included 25 points in lumbar vertebra (4 points of the corners of vertebral body and 1 point of the midpoint of pedicle along the posterior border from L1 to L5), 4 points of S1 (2 points of the corners of the upper end-plate of S1 body, 1 point of the posteroinferior corner of S1 body and 1 point of the midpoint of the pedicle) and 2 points of the radiopaque ruler for calibration. The coordinate system defined by Panjabi[18] was adopted in this study. The posterosuperior corner of S1 body origin was used as the origin. The y-axis is described by the plumb line dropped from the origin, and the z-axis pointed forward at a 90-degree angle to the y-axis.

All the points were digitized orderly into computer through a back-lit tablet (REV-B, Gito Corporation, Salt Lake City, UT). The Sigmascan software (Jandel Scientific, San Ratuél, CA) was applied for programming and computation. Using these data, the curve reconstruction and geometric characteristics were worked out.

2.1 Curves Reconstruction

To evaluate the characteristics of lumbar lordosis according to age and gender, curve reconstruction using the points on the posterior margin of vertebral bodies from L1 to S1 was performed by a geometric modeling.

For the geometrical modeling, we compared many familiar types of mathematical curve models such as cubic spline, Bezier, B-spline and NURBS. The cubic spline method was chosen for the curve reconstruction not only because it was commonly referred to as curve fitting techniques[20] but also because the derived mathematical curves pass through each data point and provide four alternate boundary conditions for selection (including clamped, relaxed, cyclic and anticyclic ones).

These digitized points were remained after the reconstruction and a line parallel to the endplate was drawn from each point in order to have a clear cut guidance for screw insertion if we progress the future study (Figure 2). Due to wide variations of the length of lumbosacral spine, we normalized all the curves by scaling the height of each curve proportionally down to the fixed length (100 mm) in order to ease the fur-

Fig 1. The 31 marked points of L1 to S1 vertebrae including 2 points of calibration ruler in each lateral radiograph.

ther analysis.

The characteristics of these curves were compared by the parameters of age and gender. The ages were categorized into three groups for comparison (below 20, 20 to 40, above 40 years old). In each age group, the curve of the mean was also drawn.

2.2 Geometric Characteristics of Lumbosacral Vertebra

From the digitized points, we were interested in the following phenomena: the most anteriorward vertebrae, the most horizontal vertebrae, the distance between the y-axis to L1, the sacral inclination angle. Regarding to the angulation, positive sign means lordosis, negative sign means kyphosis.

These data were also compared among gender and age groups (below 20, 20 to 40, above 40 years old) using student t-test and ANOVA at a 95% significant level.

The most anteriorward vertebrae were determined by the longest distance that was form the geometric center (the intersection of the diagonal line of each vertebrae) to the y-axis. The vertebral inclination angle was referred to angle formed by the end plate and z-axis.

3. RESULTS

3.1 Geometric Characteristics of Lumbosacral Vertebra

As for the most anteriorward vertebrae, the most horizontal vertebrae and sacral inclination angle, there

Fig 2. The clamped boundary conditions were adopted using 8 controlled points.

were no statistically significant differences between the male and female subjects. Only the distance from geometric center of L1 to Y axis is significantly longer in the female group (Table 1).

There were also no significant differences among the age groups for the most anteriorward vertebrae, the most horizontal vertebrae and sacral inclination angle (Table 2).

For most subjects, the most anteriorward and the most horizontal vertebrae usually occurred on the L4 and L3.

3.2 Profiles of Sacral Inclination Angle Based on Age Distribution

The distributions in sacral inclination angle do not change obviously with the increasing ages (Figure3).

3.3 Profiles of Lumbar Lordosis Based on Age Distribution

The curves of lumbar lordosis from crude data in three age groups were drawn in Figure 4. The normalized curves were shown in Figure 5. In both figures, a trend of L1 shifting backward (the direction of negative z-axis) was noted in the age group of 40 to 60 and above 60 years old. The average shifting distance away from Y-axis was 5.31 mm, 11.36 mm, and 12.63 mm, respectively. The mean value of these curves was calculated and the mean curves were drawn together in Figure 6, which demonstrated that the lordotic curves of the age group below 40 were significantly different from those of the age group above 40.

If the lumbar lordosis was described qualitatively,

Table 1. Basic data of parameters according to gender groups

	Male (45)		Female (37)	
The most anteriorward vertebrae	No.	(%)	No.	(%)
L1	1	(2%)	0	(0%)
L2	0	(0%)	3	(8%)
L3	6	(13%)	12	(32%)
L4	30	(67%)	19	(51%)
L5	8	(18%)	3	(8%)
The most horizontal vertebrae	No.	%	No.	%
L1	4	(0%)	2	(5%)
L2	3	(4%)	3	(8%)
L3	11	(30%)	16	(43%)
L4	25	(59%)	14	(38%)
L5	2	(7%)	2	(5%)
Distance from geometric center of L1 to Y axis (cm)*				
Mean (SD)	0.88 (15.98)		6.51 (16.59)	
Sacral inclination angle (Degree)**				
Mean (SD)	-37.64 (8.28)		-40.39 (8.83)	

* P value < 0.05

** P value > 0.05

the upper part was noted to be shifting backward and the lower part was noted to be more flat with increasing age. The magnitude of lordosis and the L1 back shifting were weakly correlated with the sacral inclination angle. (Figure 7)

4. DISCUSSION

Although lumbosacral curvature was considered

to be an important parameter in physiological and pathological evaluation, the understanding was still lacking[7,12,21]. Usually Cobb's angle was used, but there were many pitfalls[5]. For example, the same Cobb's angle could come from hundreds different curves[8]. For accurate interpretation especially in surgical correction of lumbar lordosis, reconstruction of the whole lumbar curvature in standing position could express more realistic facts and give us a clearer image[2,3]. In this study, we noted that reconstruction of

Fig 3. Distribution of sacral inclination angle according to age groups

Table 2. Basic data of parameters according to age groups

Age Groups (Number)	21~40 Y (26)		41~60 Y (25)		61~80 Y (31)	
	No.	(%)	No.	(%)	No.	(%)
The most anteriorward vertebrae						
L1	1	(4%)	0	(0%)	0	(0%)
L2	2	(8%)	1	(4%)	0	(0%)
L3	5	(19%)	6	(24%)	7	(23%)
L4	17	(65%)	15	(60%)	17	(55%)
L5	1	(4%)	3	(12%)	7	(23%)
The most horizontal vertebrae						
	No.	(%)	No.	(%)	No.	(%)
L1	3	(12%)	1	(4%)	2	(6%)
L2	4	(15%)	1	(4%)	1	(3%)
L3	8	(31%)	11	(44%)	8	(26%)
L4	10	(38%)	11	(44%)	18	(58%)
L5	1	(4%)	1	(4%)	2	(6%)
Sacral inclination angle (Degree)*						
Mean (SD)	-40.30 (7.10)		-40.73 (8.40)		-36.20 (9.42)	

* P value > 0.05

lumbar curves is not difficult and could be applied in the practical usage. We digitized the mid-point of pedicle because it was the starting point of pedicle screw insertion and this technique could be used in further application.

As for the most anteriorward vertebrae, the most horizontal vertebrae and sacral inclination angle, there were no statistically significant differences between the male and female subjects. Only the distance from geometric center of L1 to Y-axis is significantly longer in the female group (Table 1). It might imply that the more prominent lordotic back in female subjects be originated from the shifting of the upper lumbar portion.

Being little differences between male and female subjects, we put all the data together to analyze the differences according to age groups. From Table 2, we can note that the most anteriorward vertebrae usually located in L4 for any age groups and the most horizontal vertebrae also located in L4 or L5. L5 being the most horizontal only occurred in the age group of 61 to 80.

Comparing the sacral inclination angle and the curvatures, it is interested to note that there were no statistical differences in the sacral inclination angle among three age groups (Figure 3). The upper part of the curvatures did incline rearward in the age groups of 41 to 60 and 61 to 80 (Figure 5 and 6). These curva-

tures had the characteristics of the lower part being more flat and the upper part more rearward inclined. The age of 40 years old can be used as a demarcation.

The aging changes of lumbosacral curves might be originated from many factors, such as trauma, disc degeneration, inflammation and the biomechanical adaptation. As for the aging process, the results of the adaptive compensation of senile kyphosis cannot be neglected and the lumbar lordosis was noted to decrease in the aged people[10]. In this study, the aging changes of lumbosacral curves could be qualitatively described as the flattening of lower lumbar curve (usually from L4 to S1) and the rearward inclination of upper lumbar curve (above L3). The latter may be due to the biomechanical adaptation. This expression can explain that measurement of lumbar lordosis using only the Cobb's angle has many limitations to understand the changes of lumbar curves during aging process.

Combining the parameters in this study could give us more information about the profiles of lumbosacral curves. With the simplified technique of digitization and programming, individualized curve reconstruction should be performed for several special purposes such as surgical correction and clinical follow-up. For the former, the reconstruction was suggested to be performed in the preoperative standing X-rays.

The relationship between lumbar lordosis and

Fig 4. Distribution of raw lumbosacral curves according to age groups

Fig 5. Distribution of normalized lumbosacral curves according to age groups

pelvic tilt was reported to be weak [24,28]. However, During [7] claimed that the relations between the angle of declivity of the sacrum and radius and inclination of the lordotic curvature of the lumbar spine showed a considerably close correlation. He used L4, L5 and S1 to create the radius of lumbar curve and all the normal subjects belonged to the young age group (19 to 44 years). High correlation coefficient between the lumbar curve and the pelvic tilt was noted in some studies [15,27]. These controversial viewpoints might be based on the fact that the whole lumbar contour was influenced by the upper lumbar and the lower lumbar

curves. Gelb claimed that loss of distal lumbar lordosis is most responsible for sagittal imbalance [10]. In our study, we noted that the L1 position was weakly and negatively correlated to the sacral inclination. With the increase of the sacral inclination, the L1 went more rearward. But from the observation of curve contours and the most horizontal vertebrae in different age groups, we can imply that the adaptation of lumbar curves with age might mainly occur in the upper lumbar vertebrae. This can explain the inconsistent results obtained in the previous studies.

In this study, we did not discuss about the patients

21~40 Y : — ; 41~60 Y : - - - ; 61~80 Y : . . .
Fig 6. Mean lumbosacral curves according to age groups

with backache. However, most previous studies reported that there were no radiological differences between the subjects with and without backaches [21] although some claimed that there were differences. Therefore, for the cases needed to have curve correction in spinal fusion, we should consider the aging adaptation and the individualized characteristics before making decision about the amount of correction. The curve profile of the standing lateral radiograph is recommended as the reference of reconstruction. The situation of sitting position will not be considered unless the fusion level is to go to L5-S1.

5. CONCLUSION

The sagittal lumbosacral curves can be easily reconstructed by digitizing lateral radiographs. Although there existed individual variations, the aging changes of lumbosacral curves could be qualitatively described as the flattening of lower lumbar curve and the rearward inclination of upper lumbar curve. Understanding this evolution and geometric characteristics such as the most anteriorward vertebrae or horizontal vertebrae may help clinician to consider the appropriate lumbar curve when doing therapies. Although individual variations existed, the aging changes and the geometric characteristics such as the most anteriorward or horizontal vertebrae could be used as an important guideline during surgical correction. Applying the reconstructed individual curve to surgical correction become probable.

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