The Large Individual Differences in the Range of Hip Joint Motion Rather Than Lumbar Spine Motion Affect Dynamic Spinopelvic Rhythm

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Abstract:

Introduction: Global spinal balance and its relationship to the pelvis have received much attention, and various formulae have been used to predict postoperative spinopelvic alignment for spinal surgery. However, previous studies had limitations because no consideration was given to the dynamic factor.

Methods: Fifteen healthy adults without any lumbar disorder (group A) and 9 L4-spondylolisthesis patients (Group B) volunteered to participate in the study. Sequential images were captured with the subjects in the standing position with maximal forward bending followed by backward bending using a dynamic flat panel detector system. Spinopelvic parameters (LL: lumbar lordosis, SA: sacrofemoral angle, SS: sacral slope, PI: pelvic incidence, DP: distance of the horizontal movement of the pelvis) were evaluated. We also investigated the relationship between LL and SA (lumbar/hip [L/H] ratio) as the spinopelvic rhythm.

Results: In group A, the mean change in LL was 83.2 ± 9.5°; change in SA, 45.4 ± 16.6°; SS, 42.6 ± 8.9°; PI, 43.2 ± 7.7°; DP, 15.7 ± 3.4 cm, and L/H ratio, 3.6 ± 2.7. However, spinopelvic rhythm changed over time, because the change in LL was larger than the change in SA from the middle of the rising motion to the upright position. In group B, the mean change in LL was 50.3 ± 8.0°; SA, 56.9 ± 16.0°; SS, 27.5 ± 13.5°; PI, 47.4 ± 10.4°; DP, 12.7 ± 6.8 cm; and L/H ratio, 1.0 ± 0.5.

Conclusions: When compared with the change in LL, individual differences were largely noted in the change in SA. These results demonstrated that the range of hip joint motion under physiological conditions, unlike anatomical motion, differed substantially between individuals. Therefore, spinopelvic rhythm is dependent on the change in SA.

Keywords:

Spinopelvic rhythm, Global spinal balance, dynamic factor

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Introduction

It is generally known that the normal coronal alignment of the human spine is straight. However, the sagittal alignment of the spine and pelvis in a standardized standing position varies considerably between individuals[1,2)]. Sagittal plumb lines for spinal balance, which have been measured in various ways, have also shown wide cross-sectional variations among different volunteer and patient populations[2-8)]. Global spinal balance and its relationship to the pelvis have received increased attention because recent studies have shown that sagittal plane alignment is highly correlated with disability and quality of life[9-12)]. The analysis of sagittal balance has recently appeared to be essential in the management of lumbar degenerative pathologies, especially after spinal fusion is achieved[13-19)]. The pelvis is characterized by an important anatomic landmark. Pelvic incidence (PI) does not change after adolescence. It directly influences pelvic

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alignment and such parameters as pelvic tilt (PT), sacral slope (SS), lumbar lordosis (LL), and overall sagittal spinal balance. In the occurrence of an elevated PI, the spine adapts by increasing LL. To prevent or limit sagittal imbalance, the spine may also compensate by increasing PT or pelvic retroversion in an attempt to maintain an upright posture. Abnormal spinopelvic parameters contribute to the occurrence of multiple spinal conditions, including isthmic spondylolysis, degenerative spondylolisthesis, and deformity, and impact outcome after spinal fusion.

It is no longer acceptable to perform spine surgery without considering global spinal balance and the spinopelvic junction[20,21]. Lafage et al. have published predictive formulae that allow the calculation of postoperative PT and sagittal vertical axis values from PI, LL, thoracic kyphosis (TK), and patient's age[22]. Although preoperative planning is essential for spinal deformity surgery and various formulae are used to predict the postoperative spinopelvic alignment[23-27], these classifications and formulae have limitations because no consideration is given to the dynamic factor.

We, therefore, investigated the characteristics of spinopelvic rhythm in healthy male adults and elderly spondylolisthesis patients.

Materials and Methods

This study included 15 healthy adults and 9 spondylolisthesis patients. Group A comprised 15 healthy male adults, aged 30.6 ± 6.2 (range, 22-43) years old, with no lumbar disorder. Group B comprised 9 patients (7 males and 2 females), aged 73.26 ± 6.1 (range, 67-85) years old, with degenerative spondylolisthesis at L4, who had been scheduled for lumbar surgery. This study was approved by the ethics committee of our institution, and informed consent was obtained from all patients prior to their inclusion in the study.

Imaging with a dynamic flat panel detector system (CXDI-50RF; Canon, Tokyo, Japan) and X-ray tube (ROTANODE; DRX-1414A 1. 3/0. 6, TOSHIBA, Tokyo, Japan) was performed under the following imaging conditions: 70 kV, 4 mA, 10 ms, source-detector distance 100 cm, and 2 frames/s. Sequential images were captured with the subjects in the standing position with maximal forward bending followed by backward bending for 10 s at a constant rate. As a result, 20 lateral radiographs from L1 to the femur were obtained. The matrix size of an acquisition picture was 1110 × 1340 pixels, and the pixel size was 0.32 mm. The total radiation dose was 9.8 mGy, which was similar to that of two projections of conventional lumbar lateral imaging (10.8 mGy). For improved reproducibility of the kinetic test, the patients were given sufficient explanations regarding the procedure and how they should participate before actual imaging. Horizontal front-back movement of the pelvis was allowed, but knee joint movement was restricted.

We used ImageJ (ver. 1.47v, National Institutes of Health, USA) to analyze the images. Each point was measured three times per frame, and the average values were used for the calculation of the spinopelvic parameters. Neutral position was defined as the frame whose vertical axis was parallel to the line drawn from the posterior edge of the inferior L1 endplate to the anterior edge of the S1 endplate. Spinopelvic alignment was evaluated using the following parameters: LL, SA: sacrofemoral angle (the angle formed between the axis of the femur and the line tangent to the upper endplate of S1), SS: sacral slope, PI, DP: distance of pelvis movement (the horizontal offset between the vertical line and the posterior edge of the S1 endplate). Change in LL and SA was plotted in a chronological order with the maximum forward bending as the reference point (Fig. 1). DP was also plotted in a chronological order. For validation of the spinopelvic rhythm, we investigated the lumbar/hip ratio (L/H ratio), which was calculated by dividing the change in LL by the change in SA. We also investigated the relationship between spinopelvic parameter.

The results are presented as mean ± standard deviation. Statistical analysis was performed using Pearson's correlation. We considered $P < 0.05$ to be statistically significant in all our analyses, which were performed using SPSS version 20 (IBM, Armonk, NY, USA).

Results

The mean lumbar spine motion, hip motion, L/H ratio, DP, and other spinopelvic parameters during maximal forward bending followed by backward bending are summarized in Table 1. In group A, the mean change in LL was 83.2 ± 9.5°; SA, 45.4 ± 16.6°; SS, 42.6 ± 8.9°; PI, 43.2 ± 7.7°; DP, 15.7 ± 3.4 cm; and L/H ratio, 3.6 ± 2.7. However, the spinopelvic rhythm changed over time, because the change in LL was larger than the change in SA, from the middle of the rising motion to the upright position (Fig. 2a). In group B, the mean change in LL was 50.3 ± 8.0°; SA, 56.9 ± 16.0°; SS, 27.5 ± 13.5°; PI, 47.4 ± 10.4°; DP, 12.7 ± 6.8 cm; and L/H ratio, 1.0 ± 0.5. The spinopelvic rhythm in group B, compared with group A, remained relatively constant (Fig. 2b).

For both groups, individual differences were more marked in the change in SA than in the change in LL. Fig. 2 demonstrates the spinopelvic rhythm in each case.

Correlation between spinopelvic parameters is summarized in Table 2. No significant correlation between each parameter was observed.

Discussion

Given that sagittal plane alignment is determined by the interaction between spinal and pelvic parameters, understanding the spinopelvic balance is fundamental[28,29]. Although it is considered that proper alignment in an individual is also influenced by dynamic factors, a few reports have investigated the relationship between the spine and hip joint[30-35]. According to these reports, the kinetic changes in lumbar and hip motion vary between individuals. Spinopel-

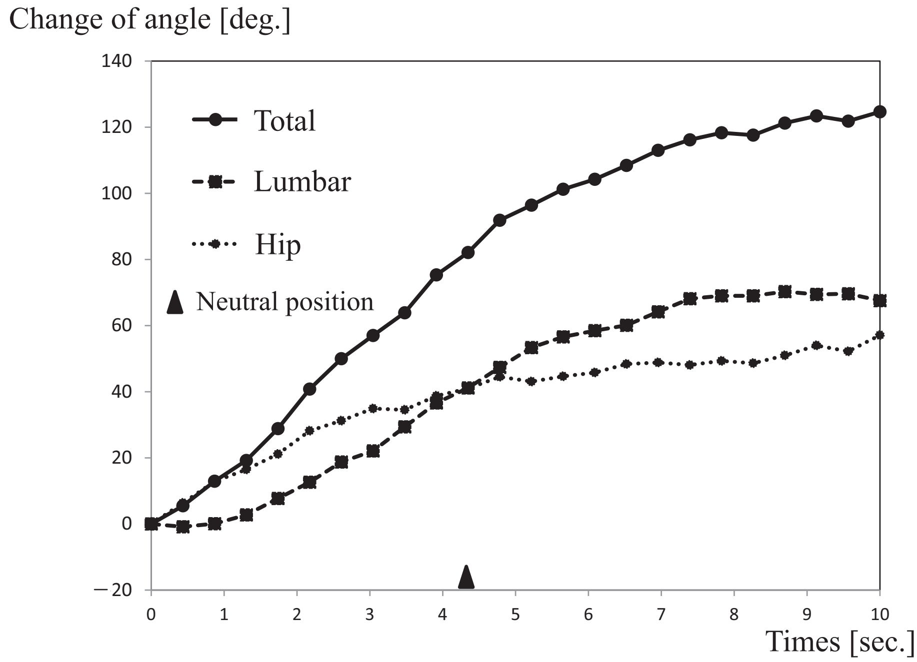

Figure 1. Plotted lumbar lordosis (LL) and sacrofemoral angle (SA) in chronological order.

Table 1. Data of the Investigated Patients.

Group A	Change of LL	Change of SA	Total	SS	PI	DP
1	67.6	61.9	129.5	36.8	45.7	15.1
2	68.5	53.5	122.0	45.2	39.5	21.3
3	74.5	9.0	83.5	45.7	40.2	10.7
4	74.7	37.7	112.4	54.4	46.8	14.3
5	77.9	55.5	133.4	34.2	41.8	13.1
6	79.1	69.0	148.1	32.8	43.7	22.7
7	80.5	46.5	126.9	48.8	47.3	16.5
8	82.7	45.4	128.2	54.3	38.8	12.4
9	84.5	53.2	137.7	39.7	39.2	15.3
10	84.9	17.9	102.8	28.1	31.6	10.6
11	88.8	26.1	114.9	27.8	29.5	19.0
12	95.6	46.9	142.5	39.6	50.5	16.2
13	95.9	57.6	153.5	48.9	40.4	13.4
14	96.4	36.4	132.8	54.4	51.4	16.5
15	96.6	64.1	160.7	47.8	62.0	18.5
Mean	83.2	45.4	128.6	42.6	43.2	15.7
STDEV	9.5	16.6	19.2	8.9	7.7	3.4

Group B	Change of LL	Change of SA	Total	SS	PI	DP
1	36.6	68.6	105.2	36.5	45.7	10.0
2	42.4	77.5	119.9	17.7	36.2	24.2
3	46.6	45.2	91.8	25.6	30.1	8.9
4	48.0	54.9	102.9	32.7	47.3	6.9
5	50.4	66.0	116.4	50.6	58.6	21.8
6	52.3	51.5	103.7	27.6	60.5	9.9
7	54.7	75.6	130.3	25.7	40.3	14.7
8	60.3	41.8	102.1	0.9	53.3	3.4
9	61.1	31.1	92.3	29.8	54.6	15.0
Mean	50.3	56.9	107.2	27.5	47.4	12.7
STDEV	8.0	16.0	12.7	13.5	10.4	6.8

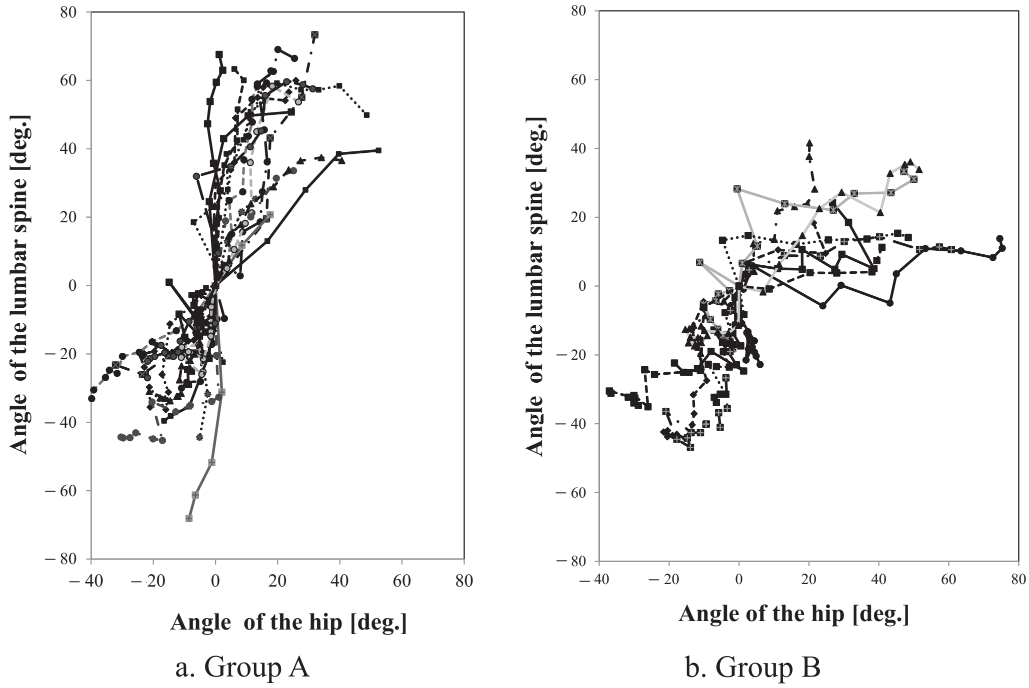

Figure 2. Relationship between lumbar lordosis (LL) and sacrofemoral angle (SA) (L/H ratio).

Table 2. Correlation between Spinopelvic Parameters.

Group A	LL	SA	SS	PI
LL				
SA	0.005 (0.985)			
SS	0.113 (0.688)	0.062 (0.826)		
PI	0.289 (0.295)	0.466 (0.080)	0.511 (0.052)	
DP	−0.462 (0.083)	−0.26 (0.927)	0.043 (0.878)	0.103 (0.715)
Group B	**LL**	**SA**	**SS**	**PI**
LL				
SA	−0.618 (0.76)			
SS	−0.345 (0.363)	0.250 (0.516)		
PI	0.466 (0.206)	−0.319 (0.403)	0.231 (0.549)	
DP	−0.207 (0.592)	0.545 (0.129)	0.405 (0.279)	−0.80 (0.839)

Pearson's correlation coefficient between each spinopelvic parameter. All satistically significant correlations are bolded.

vic rhythm is another aspect of the understanding of spinal kinematics and spinal motion with respect to dynamic sagittal alignment[31,36]. Esola et al. reported that lumbopelvic ratios in healthy subjects for early, middle, and late forward bending were 1.9, 0.9, and 0.4, respectively. This means that the rate of hip movement gradually exceeds lumbar movement as forward bending occurs[31]. Hasebe et al. also reported on lumbopelvic rhythm. In this report, lumbopelvic ratios for early, middle, and late forward bending were 4.0, 1.0, and 0.4, respectively[30].

The feature of this study was that while back and forth movement of the pelvis was allowed, the knees were restricted to the extended position alone. As in previous reports, in this study, the early movement from maximum flexion started with the pelvis, and the percentage of movement of the lumbar spine was rapidly increased. The movement of the lumbar spine was 83.2 ± 9.5°, and individual differences were relatively small based on the standard deviation in group A. On the other hand, individual differences were notable regarding the movement of the hip joint and the movement distances of the pelvis back and forth. In particular, the movement of the hip joint was found to have a considerable variation with a standard deviation of 16.6° even in group A, which comprised healthy adults. Furthermore, the hip joint changed by more than 5° even after movement of the lumbar spine stopped at the end of extension movement in 5 cases in the healthy group. Even among young healthy individuals, the position of the center of gravity and movement in the anterior-posterior direction of the pelvis were found to differ individually. This greatly affected the lumbopelvic rhythm (Fig. 3). If the anterior movement of the pelvis is increased by the extension motion, the

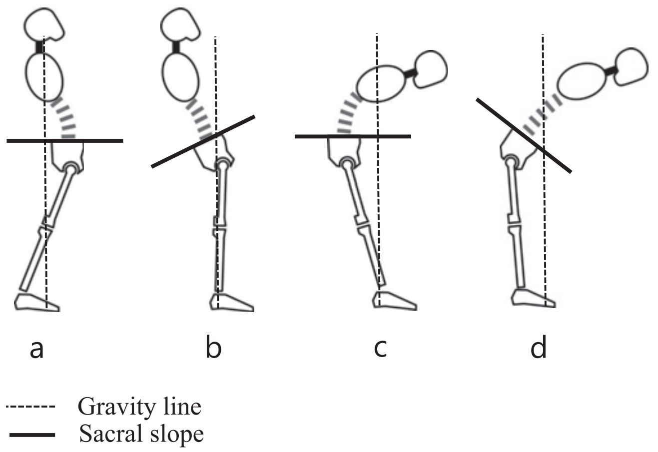

Figure 3. Pattern of sagittal balance.

change in SS decreases and the hip joint moves even after the maximum lordotic posture has been attained. The center of the gravity line is reported to pass through the center of the pelvis and the foot in the normal standing position[28]. However, it can be seen that the lumbar spine is more curved in a kyphotic manner if the center of gravity is located posteriorly and the pelvis is located behind the center of the gravity line. It is also reported that the movement of the hip joint becomes smaller in the presence of a tight hamstring[3]. From the above, dynamic alignment is not constant even in a healthy person. We believe that these factors influence the difference in rhythm individually.

We considered that the L/H ratio in group B was smaller because of compensatory hip movement as in previous studies. As the elderly age further, LL decreases, TK progresses, and the gravity line gradually shifts forward[28]. These changes make lumbar spinopelvic rhythm more complicated for elderly patients with lumbar spine disease. In current correction surgery for adult deformity, spinal fusion is indispensable. When the compensating function exceeds its limit, it is considered that spinal alignment is broken, and the group that can acquire normal alignment also acquires a higher quality of life[11]. We consider that individual differences in the range of hip motion and the back and forth distance of the pelvis could contribute to the magnitude of future compensatory functions. Therefore, although appropriate alignment of individuals is affected by lumbopelvic rhythm, it is difficult to generalize and standardize lumbopelvic rhythm in spinal fusion surgery.

Conclusion

Static alignment using sagittal spinopelvic parameters in the upright position is an important index in spinal fusion surgery. However, an individual's proper alignment settings should be determined with reference not only to standardized static alignment but also to dynamic alignment. Even among young healthy individuals, there are large individual differences in the range of hip joint motion compared with lumbar spine motion. The position of the center of gravity and movement in the anterior-posterior direction of the pelvis differed individually, and this greatly affected the lumbopelvic rhythm. We believe that the allowable range of proper spinal alignment varies depending on individual spinopelvic rhythm. In recent years, the total sagittal alignment from the cervical vertebra to the ankle has gradually become an important topic, and three-dimensional alignment analysis is also progressing[37]. Hence, it is necessary to study the relationship between spinal sagittal alignment and quality of life with consideration for dynamic factors.

Conflicts of Interest: The authors declare that there are no relevant conflicts of interest.

Author Contributions: Katsuhito Yoshioka wrote and prepared the manuscript, and all of the authors participated in the study design. All authors have read, reviewed, and approved the article.

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