Changes of cervical sagittal alignments during motions in patients with cervical kyphosis

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Abstract
Changes of cervical sagittal alignment during motion in cervical kyphosis patients have never been published before. This study was to investigate the changes and provide a better reference for orthopedic treatment.

Randomized double-blind repeat trial was carried out on 60 patients with cervical kyphosis. On standard position, hyper flexion, and hyper extension sagittal radiographs, the following measurements were made: the C2–7 vertebral body spatial alignment angle (∠A), C2–7 vertebral lower terminal lamina tilt angle (∠B), C2/3 to C6/7 segmental intervertebral space angle (∠C), the distance from the posterior edge of odontoid to C7 vertebral body (D value), and the difference of angle A, B, and C between cervical flexion and extension movement. Another 60 healthy volunteers were enrolled, of whom the cervical curve apex was determined using Borden’s method to compare change and distribution characteristics to patients with cervical kyphosis and C value.

In standard lateral position, ∠A was positive and increased from C2 to C7. In hyper extension position, ∠A decreased with reducing amplitude from C2 to C7 compared with the standard position, whereas in hyper flexion position, the average value of ∠A increased with decreasing amplitude from C2 to C7. ∠B followed similar change regularities as ∠A with a larger mean value. In cervical flexion and extension movement, ∠A change of upper vertebral body (∠D) was almost equal to ∠A change of lower vertebral body and ∠C change between the adjacent 2 vertebral bodies (∠E). The curve apex distribution was almost between C4 and C5 in cervical kyphosis patients. A significant difference was observed between cervical kyphosis patients and normal people in C value and D value.

The correction of the cervical kyphosis can be carried out from the apex of the cervical spine that provides a solid theoretical foundation for the correction of the cervical kyphosis.

Keywords: cervical curve apex, cervical kyphosis measurement, hyper extension, hyper flexion, radiograph, segmental intervertebral space angle, vertebral lower terminal lamina tilt angle, vertebral spatial angle

1. Introduction
Normal sagittal cervical balance is maintained by physiological lordosis and the anterior, posterior intervertebral disc heights. The balance contributes to the sagittal cervical curvature.[1–3]
When it is disrupted, it could evolve into cervical kyphosis which is a syndrome induced by various causes and could present as loss of multiple segmental cervical lordosis, cervical extension torque moment changes into flexion torque moment, vertebral body height decreases, facet joint dislocation, cervical instability, accompanied by local vertebral body backwards, cervical stenosis, and adjacent segment faded. Subaxial cervical kyphosis most often occur in the sagittal plane that may develop secondary to advanced degenerative disease, trauma, neoplastic disease, or surgery.[4,5] Nowadays, the research on the vertebral body and the relationship between vertebral bodies is relatively rare, particularly in cervical kyphosis. Correction of cervical kyphosis is lack of unified standards and has high surgical risks, which makes it hard for surgeons to operate accurately and predict postoperative recovery.[6–10] To find the motion law of cervical spine and the change of head gravity line, we have measured sagittal view of each position of the patients with cervical kyphosis, so as to provide a accurate theoretical guidance for the correction of the deformity.

2. Materials and methods
2.1. Basic information
With our Institutional Review Board’s approval and patients’ agreement, 60 patients with cervical kyphosis were included in our study: 28 male patients and 32 female patients aging from 18 to 76 years with a mean age of 50 years. All patients had taken standard, hyper flexion, and hyper extension sagittal views, respectively. Patients with cervical spine trauma, tumor, vertebral body damage, severe vertebral hyperplasia, or vague vertebral
2.2. Measurement methods

All radiograph films were directly uploaded into a computer. The measurements were made using Photoshop CS3.0 thrice by each of the three experienced spine surgeons who were blind to the study design and clinical symptoms of each case separately. We measured the C2–3 cervical endplate angle to represent C2 vertebral space baseline; because of irregular C2 vertebral body, we measured cervical endplate angle to represent C2 vertebrae space angle. C2–7 vertebral lower terminal plate tilt angle (∠B) (the angle was conducted by extending the inferior endplate line and the radiographic baseline parallel line until they intersect), C2/3–C6/7 intervertebral angle (∠C) (the angle between the lines connecting superior and inferior vertebral endplates within the same intervertebral space segment). Identifying cervical vertebral curve apex using Borden’s method, line A was drawn connecting the posterior edges of all vertebral bodies, line B was drawn from the posteriuperior edge of the odontoid to the posterosuperior edge of C7 vertebrae, from the point indicating the widest gap between lines A and B, a perpendicular line C was drawn representing cervical spine physiologic curve depth (C value). The junction of lines A and C indicated the cervical curve apex. D value was the distance between the posterior of odontoid process and the posterior of C7 vertebrae. Tangent angle ∠F indicated the cervical kyphosis (±F: the angle between tangent lines of the posterior of 2 adjacent vertebral bodies) (Fig. 1).

2.3. Statistical analysis

All data measured in excel form were recorded into computer, processed by Statistical software SPSS.19. From hyperextension to hyperflexion movement, variations of angle A and B of different cervical segments were analyzed by 2 independent sample t test. Comparison of angle value D and E was conducted by paired t test. For cervical kyphosis patients and the control group, D value and t value were analyzed by 2 independent sample t test.

3. Results

Tables 1 to 3 indicated standard, hyper flexion, and hyper extension sagittal view spatial alignment angle (±A) and vertebral lower terminal lamina tilt angle (±B). In standard position, each vertebral body spatial alignment ±A mean was positive that increased from C2 to C7. In the hyper extension position, the average value of ±A was smaller than that of the standard position, and the reduction amplitude decreased from C2 to C7. The average value of these 2 was almost the same in C7 vertebral body. Overall, in the hyper extension position, the average value of ±A increased from C2 to C7 as the same as the standard position, except negative C2 mean value. In the hyper flexion position, the average value of ±A was larger than the standard position, and the improvement of amplitude decreased from C2

Figure 1. ∠A, the angle between the line connecting the midpoints of vertebral posterior and anterior edge and the line parallel to the radiograph baseline level. ∠B, the angle between the inferior endplate line and the line parallel to the radiographic baseline. ∠C the angle between the lines connecting superior and inferior vertebral endplates within the same intervertebral space segment. C value, a perpendicular line is drawn from the widest gap point between lines A and B. D value (the distance between the posterior of odontoid process to posterior of C7 vertebrae), ∠F, the angle between the posterior of 2 adjacent vertebral bodies.
to C7. The average value of these 2 was basically the same in C7 vertebral body. The difference was that the average value of ∠A decreased from C2 to C7. ∠B followed similar change regularities as ∠A with a larger mean value (Fig. 2). The change of ∠A (the ∠A difference between hyper flexion and hyper extension) decreased from C2 to C7. The change of ∠B (the ∠B difference between hyper flexion and hyper extension) had the same change trend. No significant difference was observed between ∠A and ∠B angle changes through the t test (C3, t = -0.606, P = 0.587; C4, t = -0.587, P = 0.731; C5, t = 0.930, P = 0.890; C6, t = -1.102, P = 0.788; C7, t = -0.841, P = 0.113) (Fig. 3). In the cervical flexion and extension movements, ∠A change of upper vertebral body (∠D) was equal to the summation of ∠A change of lower vertebral body and ∠C change between the 2 adjacent vertebral bodies (∠E). ∠D and ∠E showed no significant difference through the paired t test (C2, t = 1.637, P = 0.103; C3, t = 1.127, P = 0.261; C4, t = 1.401, P = 0.163; C5, t = 1.891, P = 0.060; C6, t = 1.831, P = 0.069) (Fig. 4). In the standard position, the curve apex of cervical spine distributed most at C4 (42%) and C5 (44%), a few at C3 (1%) and C6 (13%). In the cervical flexion and extension

| Table 1 |
| Standard lateral view indicating individual vertebral segment spatial alignment and inferior terminal lamina tilt angles. |
| C2A | C2B | C3A | C3B | C4A | C4B | C5A | C5B | C6A | C6B | C7A | C7B |
| Maximum, ° | 11.7 | 15.4 | 17.5 | 20.7 | 28.1 | 28.6 | 33.1 | 33.0 | 31.8 | 32.8 | 37.5 | 39.6 |
| Minimum, ° | -15.3 | -28.0 | -28.0 | -11.0 | -15.5 | -5.0 | -5.3 | 6.3 | 6.8 |
| Mean, ° | 4.8 | 3.0 | 3.0 | 2.7 | 8.0 | 7.8 | 13.1 | 11.7 | 17.0 | 17.2 | 23.1 | 24.9 |
| SD, ° | 8.9 | 6.3 | 10.0 | 11.0 | 12.9 | 13.2 | 15.5 | 14.7 | 17.0 | 17.5 | 22.4 | 24.2 |

| Table 2 |
| Hyper flexion lateral view indicating individual vertebral segment spatial alignment and inferior terminal lamina tilt angles. |
| C2A | C2B | C3A | C3B | C4A | C4B | C5A | C5B | C6A | C6B | C7A | C7B |
| Maximum, ° | 15.4 | 17.5 | 20.7 | 13.3 | 28.1 | 28.6 | 33.1 | 33.0 | 31.8 | 32.8 | 37.5 | 39.6 |
| Minimum, ° | -39.0 | -30.2 | -37.1 | -19.1 | -28.0 | -11.0 | -15.5 | -5.0 | -5.3 | 6.3 | 6.8 |
| Mean, ° | -6.0 | 2.1 | 2.7 | 8.0 | 7.8 | 13.1 | 11.7 | 17.0 | 17.2 | 23.1 | 24.9 |
| SD, ° | 10.8 | 11.1 | 10.0 | 10.2 | 8.6 | 9.3 | 7.7 | 8.3 | 7.3 | 7.4 | 7.4 | 7.1 |

| Table 3 |
| Hyper extension lateral view: indicating individual vertebral segment spatial alignment and inferior terminal lamina tilt angles. |
| C2A | C2B | C3A | C3B | C4A | C4B | C5A | C5B | C6A | C6B | C7A | C7B |
| Maximum, ° | 64.3 | 67.0 | 61.1 | 61.5 | 55.3 | 55.0 | 48.6 | 47.3 | 44.5 | 40.6 | 47.2 | 49.6 |
| Minimum, ° | 11.7 | 15.4 | 12.6 | 14.8 | 14.8 | 14.3 | 11.2 | 11.8 | 8.3 | 5.8 | 7.8 | 7.4 |
| Mean, ° | 35.4 | 36.2 | 35.0 | 36.7 | 32.8 | 33.5 | 28.6 | 26.5 | 26.1 | 27.2 | 26.8 | 29.2 |
| SD, ° | 11.2 | 11.2 | 10.4 | 10.2 | 8.8 | 9.0 | 8.6 | 9.3 | 8.4 | 9.2 | 9.0 | 9.4 |

Figure 2. In standard position, each vertebral body spatial alignment ∠A average is positive that increases from C2 to C7. In the hyper extension position, the mean value of ∠A decreases compared with the standard position, and the reduction amplitude decreases from C2 to C7. The average value of the 2 is basically the same in C7 vertebral body. Overall, the average value of ∠A increases from C2 to C7 gradually the same as the standard position, just average C2 value is negative. In the hyper flexion position, the average value of ∠A increases compared with the standard position, and the increased amplitude decreases from C2 to C7. The average value of the 2 is basically the same in C7 vertebral body. The difference is that the average value of ∠A decreases from C2 to C7. ∠B follows similar change regularities as ∠A with a larger mean value than ∠A.

Figure 3. The change of ∠A (the ∠A difference between hyper flexion and hyper extension) decreases from C2 to C7. The change of ∠B (the ∠B difference between hyper flexion and hyper extension) follows the same change trend.
movements of cervical kyphosis patients, the curve apex was stably distributed between C4 and C5. This was the same with healthy people (Fig. 5) A significant difference was observed between cervical kyphosis patients and healthy people in C value ($t = 0.209, P = .045$) and D value ($t = 2.928, P < .05$) (Table 4).

4. Discussion and conclusions

Normal cervical spine has certain physiological lordosis in standard sagittal position. This physiologic arch is mainly formed and maintained by the anteroposterior discrepancy of the intervertebral disc height and it is the basis and security of keeping the cervical spine healthy. The height of the anterior edge of the vertebral body is also an important factor of maintaining the physiologic curvature of the cervical spine. However, once the spatial position of vertebral body in sagittal plane changes, the original state of equilibrium will be broken, the normal physiological lordosis will gradually lose and the cervical kyphosis will develop at different degrees. Nowadays many reasons can cause cervical kyphosis, among which the loss of the vertebral body height caused by cervical vertebral fracture is the most common one.

The cervical curvature of patients with cervical kyphosis alters without change of the shape of the vertebral bodies. In the cervical flexion and extension movements, the changes of vertebral spatial position result in the alteration of the anterior and posterior edges of the intervertebral disc height, and the coordinated motion of the facet joints leads to the cervical physiological curvature changes, which is the same as the normal people, except the different change amplitude.

In our study, the $\angle A$ value of each cervical vertebra was positive and gradually increased from C2 to C7 in the standard position of cervical kyphosis patients. This showed that the anterior downward tilt angle of cervical body gradually increased from C2 to C7, complied with the physiological lordosis of cervical spine. In the hyper extension position, the average value of $\angle A$ was smaller compared with the standard position, the reduction amplitude decreased from C2 to C7, and $\angle A$ value of C2 and C3 were negative. Overall, the average value of $\angle A$ increased from C2 to C7 gradually the same as in the standard position. This indicated that vertebral body moved clockwise with decreasing tendency of anterior downward gradient during hyper extension, and the rotation angle of the upper vertebral body was slightly larger than that of the lower level in the sagittal plane, and C2 and C3 vertebral bodies even tended to tilt anteriorly and upwardly. This showed an increase in cervical lordosis. In hyper flexion movement, the average value of $\angle A$ increased compared with the standard position, and the increasing amplitude decreased from C2 to C7. However, the mean $\angle A$ value of C2-C7 was gradually decreased, which was contrary to the neutral position and the hyper extension position. This suggested that the cervical vertebra rotated counterclockwise during hyper flexion movement, the rotation amplitude of the upper vertebra in sagittal plane was slightly larger than that of the lower vertebra, which was the same in hyper extension movement and resulted in the cervical curvature turned from lordosis to kyphosis. The changes of $\angle B$ were similar to that of $\angle A$, but the average value was higher than that of $\angle A$, which indicated that vertebral body was not rectangular and the anterior edges tended to extend anteriorly and downwardly, and this was associated with cervical lordosis and orthostatic weight-bearing (Fig. 2).

Figure 3 compared the difference values of $\angle A$ and $\angle B$ in patients with cervical kyphosis between the extension and flexion...
positions, reflecting the motional amplitude and changes of cervical vertebra in the sagittal plane more clearly. On the whole, angle changes of the vertebral bodies decreased gradually from C2 to C7, showed that the rotation range of the vertebra in sagittal plane also reduced gradually. Moreover, t test results showed no significant difference between \( \angle A \) and \( \angle B \) variables of each vertebra segment \( (P > .05) \), suggesting that vertebral inferior terminal lamina and vertebral body itself had the same variation in the cervical flexion and extension movement in cervical kyphosis, therefore inferior terminal lamina movement can reflect movement of the vertebral bodies in the sagittal plane.

Figure 4 compared the \( \angle D \) and \( \angle E \) values of cervical kyphosis patients during hyper flexion and extension, showing that \( \angle D \) and \( \angle E \) values were similar within the same vertebral segment, with no significant difference \( (P > .05) \). This demonstrated that spatial alignment change of the upper vertebra was a gradual superimposing result of those occurring within the lower vertebra. \( (C2 \angle D = C7 \angle D + \text{variable} \angle C + \text{variable} \angle C5/6 \) variable \( \text{variable} \angle C + \text{variable} \angle C4/5 \) variable \( \angle C + \angle C2/3 \) variable \( \angle C) \).

Our study showed that 86% of cervical curvature apex positions located between C4 and C5 in cervical kyphosis patients while 100% in normal people. Figure 5 showed that cervical curve apex mainly lied between the upper boundary of C4 and lower boundary of C5 in both normal people and patients with cervical kyphosis, and during hyper flexion and extension, the apex distribution remained unaffected or by 1 vertebra at most.

Table 4 compared C2 to C7 vertical distance D value and the C values measured by Borden’s method between normal people and patients with cervical kyphosis. The results showed that there were significant differences in D values \( (P < .05) \) and C values \( (P < .05) \) between normal people and patients with cervical kyphosis. This result indicated that it was the physiological curvature of the normal human cervical spine, which resulted the C values and D values in the normal range. However, in patients with cervical kyphosis, physiological lordosis disappearance, and even becoming kyphosis led to straightened cervical vertebra and loss of physiological curvature. C values were significantly decreased even to a negative value and D value also decreased as the vertebral body became straight.

The cervical spine’s sagittal profile represented a balance between the anterior (vertebral body, intervertebral disc, anterior longitudinal ligament) and posterior (lamina, facets, posterior ligament) elements. Pathologically, weakened pull strength of cervical posterior structure or increased pressure of anterior structure led to the changes of vertebral spatial positions, caused lowered anterior and raised posterior height of intervertebral discs, and finally can resulted in anterior vertebral cartilage necrosis, vertebral asymmetry growth, and vertebral wedge change which can cause cervical kyphosis. Our study demonstrated that in hyper flexion and extension movements of cervical kyphosis patients, dynamic cervical curvature change was based on a central apex \( (C4 \text{ or C5}) \). Vertebral rotation and displacement in the sagittal plane caused the change of anterior, posterior vertebral disc height, and cervical curvature. The rotation amplitude of the upper vertebra during dynamic flexion and extension movements was a superimposing result of the lower vertebra’s rotation amplitudes, with the vertebral body shifted anteroposteriorly in the sagittal plane at the same time, the curvature of cervical vertebra stayed unchanged. We thought that cervical vertebra movement was a rotation and shift based on a central apex in the sagittal plane during dynamic flexion and extension. Although in the beginning, cervical kyphosis was recoverable, but with further exacerbation to severe or rigid kyphosis, vertebra and facet joints got fusion and made the corrective surgery much harder. In cervical kyphosis, there was an abnormal vertebral rotation in the sagittal plane and orthopedic correction surgery was performed to regain normal spatial alignment of each cervical segment and cervical physiological curvature. This study revealed the law in the cervical spine motion of patients with cervical kyphosis, and verified that the corrective surgery was feasible and effective, and it could act as a good reference for the correction of cervical kyphosis.[14–16]

Measurement of spatial alignment angle and vertebral lower terminal lamina tilt angle and the research on the relationship between them during the movements have important clinical significance in patients with cervical kyphosis. It not only provides accurate reference and standard for the correction of the cervical kyphosis, but also guides the extent of the correction. In kyphosis corrective surgery, the vertebral inferior terminal endplate angle is the main reference of anterior intervertebral space distraction amplitude, whereas preoperative correction design is based on vertebral body spatial alignment angles which can connect the surgery with the preoperative plan. Cervical vertebra movement is a rotation and shift based on a central apex \( (C4 \text{ or C5}) \) in the sagittal plane, suggesting that the correction of the cervical kyphosis can be carried out from the apex to both ends of the cervical spine. So, this study provides a theoretical foundation for the correction of cervical kyphosis.

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