Characteristics of Sagittal Vertebral Alignment in Flexion Determined by Dynamic Radiographs of the Cervical Spine

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Abstract
Study Design. This study was conducted to depict the change patterns of intervertebral motion of the cervical spine during flexion, upright, and extension positions using dynamic radiographs. Special interest was focused on the flexion position.

Objectives. To find reliable criteria for judging the normal intervertebral flexibility based on a survey of the normal population.

Methods. The lateral dynamic radiographs of 75 normal subjects were analyzed by digitization and computer calculation. The characteristics of intervertebral positions were investigated using flexion radiographs.

Results. From extension to flexion, the angles of intervertebral angular displacement changed from lordosis with different degrees to nearly 0°, which means the adjacent endplates are almost parallel, except at C1-C2; the intervertebral translation changes from slightly retrolisthetic to zero displacement. Using C2-C3 as a baseline to calculate the intervertebral differences of angular displacement and translation in flexion radiographs, nearly all the intervertebral differences of angular displacement were less than 7°, and those of translation were less than 0.06 mm.

Conclusions. Qualitative changes from extension to flexion and quantitative values of intervertebral differences in flexion radiographs help define the normal flexibility of the cervical spine more accurately.

Abnormal motion, both hypermobility and hypomobility, in flexion/extension of the lumbosacral and cervical spine has long been interpreted as a sign of instability, which was considered to be a significant contributor to back and neck pain. 2,11,17,21,23 A number of radiographic motion studies, including stereophotogrammetry and sagittal dynamic radiographs, have been done to define normal flexibility. 3,4,6,9,10,20,22 Most of these studies used active motion and measured total segmental flexibility in normal subjects. In addition, Dvorak et al 7 developed a computer-assisted method to calculate segmental angular displacements and translations and compared passive flexion/extension radiographs among...
different disease categories. Because of the wide variations of the normative values from age, gender, and degeneration, many qualitative descriptions and quantitative data for judging instability have been debated. These wide variations also have limited clinical application of instability criteria. For more precise evaluation, some authors have emphasized the self-comparison such as translation/rotation ratio or the motion proportion in each level and the intervertebral differences. These studies, however, also showed wide normal variations because of the complicated and noncomputerized measuring procedure.

Finding a more reliable aspect to determine the criteria of instability is very important. From previous studies of lumbosacral flexibility, it was noted that the intervertebral relation of the lumbosacral spine in flexion radiographs was nearly parallel, with zero displacement. Therefore, by using flexion radiographs, the level of abnormal flexibility can be found more easily through self-comparison based on the data at L3-L4. The individual differences were much less varied than those using total flexibilities. Both lumbar and cervical lordosis are secondary curves that begin to appear during the fetal period and become noticeable at infancy. The lordosis further increases as a child begins to walk. There are many similarities between these two curves. For example, both provide the most mobile segments and are frequent sites of trauma, disc problems, degeneration, stenosis, and instability. In the history of clinical and basic studies, there are many similar approaches used to discuss the instability of the lumbar and cervical spine. We thus applied the similar concept to test the flexibility of the cervical spine. Therefore, the purpose of this study was to investigate the normal behavior of cervical spinal motion between the flexion, upright, and extension positions, thus establishing a more reliable and sensitive criteria for diagnosing segmental instability.

Materials and Methods

One hundred volunteers without significant neck pain were randomly selected from the Health Examination Ward in the National Cheng Kung University Hospital between October 1994 and September 1995. Excluding the radiographs that indicated kyphosis, scoliosis, spondylolisthesis, and fusion, 75 subjects were included in the study. Their average age was 47 years (range, 20-77 years). There were 44 men and 31 women. In this study, significant neck pain was defined as pain that resulted in the patient having to limit work and recreational activities or that caused the patient to seek medical help. For each patient, one anteroposterior and three lateral radiographs in the flexion, upright, and extension positions were prepared. The anteroposterior film was used for excluding scoliosis. The three sagittal films were used for analysis of cervical rhythm.

With each subject in a sitting posture, the thorax and pelvis were fixed by straps with the back against the back of the chair (Figure 1). Subjects were instructed to hold their shoulders bilaterally as low as possible to radiographically view the cervical-thoracic junction. Then neck flexion and extension were actively performed, and the corresponding lateral radiographs with a tube-film distance of 150 cm were prepared. In addition, a specially designed calibration radiopaque ruler was placed at the middle of the back of the neck to eliminate errors from graphic magnification. Digitization and measurement procedures followed the computer-assisted method used in the previous study of the lumbosacral spine.

For each film, 24 points, including 21 points of vertebral bodies and three fixed points of the radiopaque calibration ruler, were marked for digitization by a senior resident (Figure 2). Specific points were chosen for C1 and C2. At C1, the posterior margin of atlas and lowest end of spinous process was used; at C2, two points at the base of odontoid process and one point at posteroinferior lips were used. For typical cervical vertebrae from C3-C7, two points at the tips of the posterior Luschka remnants and one point at the posteroinferior angle were chosen. The vertebral body was regarded as a rigid body, and these points were checked by overlapping the related films. All of these points were digitized through a back-lit tablet.
(Jandel Scientific; Numonics Corp., Montgomeryville, PA) with a resolution of 0.1 mm, and the data were processed by a PC with the SigmaScan software (Version 3.92; Jandel Scientific; San Rafael, CA). These digitized points were transformed into coordinate data points. The coordinate system defined by Panjabi et al. was applied in this study. The positive z-axis is directed anteriorly along a line from the posterior inferior body corner to the anterior inferior body corner of the lower vertebra. The positive y-axis is directed superiorly, and the positive x-axis was directed toward the left. A clockwise angular displacement, as seen from the origin along a positive axis, was considered positive, making flexion a positive angular displacement about the x-axis. The appropriate segmental angular displacement and translation were followed.

From C2-C3 to C6-C7, the angular displacement between two segments was formed by the four points of two adjacent vertebral bodies surrounding the intervertebral disc. The translation was defined as the distance from the posteroinferior point of the vertebra above to the line perpendicular to the line formed by the upper two corners of the vertebra below. The angle between C1-C2 was formed by the two inferior points of C1 and the two superior points of C2. For the translation between C1-C2, two steps were taken. First, the midpoint of the two anterior points of C1 was marked. Then the translation was defined as the distance from the midpoint in C1 to the line perpendicular to the line formed by the upper two corners of C2.

Back to Top

Measurement.

All calculations were done using a Fortran program. The basic measurements were calculations of all the static intervertebral angular displacements and translations in different postures. Then the total flexibility (dynamic angular displacement and translation) at each vertebral level was calculated from the difference between flexion and extension positions. Special attention was given to the relations and characteristics of adjacent vertebrae based on the C2-C3 level in flexion radiographs.

The procedures of marking points were performed by an experienced resident. To test the measurement errors of segmental motion from flexion to extension, one set of radiographs was measured five times, with the points redigitized each time. Standard deviations for these five separate measurements from C1-C2 to C6-C7 were 0.53, 0.51, 0.25, 0.21, 0.27, and 0.46, respectively. Differences in values between levels can be attributed to radiograph quality and degree of repeatability. As expected, C1-C2, C2-C3, and C6-C7 have larger variations than seen in C3-C6.

For the convenience of comparison, the lordotic angle was defined as positive, whereas the kyphotic angle was defined as negative. For translation, a positive value meant anterior translation (anteolisthesis), whereas a negative value meant posterior translation (retrolisthesis). A repeated measures analysis of variance at a significance level of 5% was used for analysis.

In this study, C2-C3 was used as a baseline to delineate the characteristics of the normal physiologic maximum intervertebral angular displacement and translation in the flexion position.

Back to Top

Results

The data for C6-C7 was not available for 10 subjects because their C7 was not visible in the radiographs. The following results were derived from 75 subjects.

Back to Top

Flexion-Extension Rhythm.

The mean values (standard deviations) of angular displacement and translation at each level are summarized in Table 1. For intervertebral angular displacement, the differences among the three groups (flexion, upright, and extension) at the same corresponding levels were all statistically significant (P < 0.001). For intervertebral translation, most of the differences between the three groups (flexion, upright, and extension) at different levels were statistically significant (P < 0.001) except at C1-C2 between flexion and upright (P = 0.054) and C6-C7 between upright and extension (P = 0.06).

Table 1

From extension to flexion, the angles of intervertebral angular displacement changed from lordosis with different degrees to nearly 0° degrees, which means the adjacent endplates are almost parallel, except at C1-C2, which had a different definition of angular displacement, so it is discussed separately (Table 1). From C2-C7, the intervertebral angular displacement in the flexion position had similar small negative values, approaching 5° (Figure 3).

From extension to flexion, the intervertebral translation changes from slightly negative to slightly positive except at C1-C2, which had a different definition of angular displacement and is discussed independently. From C2-C7, the intervertebral translation in the flexion position had small positive values approaching 0.3 mm (Figure 4).

Intervertebral Difference in Flexion.
When C2-C3 was used as a baseline to calculate the intervertebral differences of angular displacement and translation in the flexion position, nearly all the intervertebral differences of angular displacement were less than 7°, and those of translation were less than 0.06 mm except at C6-C7, which still had approximately a 0.23-mm difference. C1-C2 was not included (Figure 5).

Frequency Distribution in Total Flexibility.
The frequency distribution of total flexibility in different levels is expressed in Figure 6. In most cases, total translation was between 1-3 mm, and total angular displacement was between 10-20°.

Discussion
Instability of the lumbosacral and cervical spine from either degeneration or trauma has been thought to be a significant contributor to lower back and neck pain.11,17,18,23 The American Academy of Orthopedic Surgeons defines instability in the following way: "Segmental instability is an abnormal response to applied loads, characterized by motion in motion segments beyond normal constraint."! Although this definition can include all present definitions of instability, it does not give a reliable guide to diagnose segmental instability. Usually, disagreements of instability come from the variable correlation between clinical symptoms and roentgenographic signs. The wide variations in total flexibility that most previous papers have mentioned also made the diagnosis of unstable segments controversial.9 Therefore, it is important to collect normal data in a quantitative and qualitative manner, thus determining reliable criteria from extension-flexion radiographs, which are a routine part of clinical examination.

Dvorak et al5 used the computer-assisted method to determine the angular displacement and translation in each intervertebral segment. Beginning with the extension view, four lines were drawn tangential to the four sides of the vertebral body. Their intersections provided four corner points. Then each vertebra on the flexion view was superimposed over its marked image on the extension view, and the lines were copied from one to the other. The positions of these four corner points then were entered into the computer using a digitizer. In this measuring procedure, the unrecognized borderline of image of the vertebral body may produce possible human error. In the present study, the "self-comparison" aspect was used, and the calibration radiopaque ruler was placed at the back of the neck to eliminate errors from graphic magnification. The coordinate of desired points then were digitized directly into the computer, which made this data much more accurate.

The cervical and lumbar spines are secondary curves. Because they are the most mobile parts of the spine, the authors believe that the alignment of lumbar and cervical vertebrae tend to become straight and parallel in flexion posture. In a normal lumbar spine, there are rhythmic changes of intervertebral relations from extension to flexion.15 From extension to flexion, the intervertebral angular displacements approached 0° from the lordotic position, and the translation changed from slightly retrolisthetic to...
zero displacement. In this study, we also noted that the cervical vertebral movement was slightly from a slightly retrolisthetic position to a neutral position when changing from extension to flexion and the displacement of intervertebral angular changed from lordotic to nearly 0° with slight kyphosis.

The results of range of motion in the current study confirm data reported previously. As found in other studies, the largest sagittal motion was between C4-C5 and C5-C6, and least was at C2-C3 (Figure 7). In Figure 7, most studies used active motion to calculate segmental angulation and got consistent data. Dvorak et al. 4 7 obtained an extensive range of motion of the cervical spine with passive flexion/extension examination. The aging changes of the cervical spine should be similar at each level, if no trauma affects a specific level. 4,5,8,16 How to detect an unstable level is very important. Because the wide variations in total flexibility make it impossible to define instability, self-comparison was applied in the diagnosis of the proportion of angular and translational displacements. 9,16,19 In the present study, the intervertebral differences using C2-C3 as a baseline reference were minimal in normal flexion radiographs, similar to the findings in the previous study on the lumbosacral spine. 15 C2-C3 was used as the baseline because most of the trauma, degenerative changes, and instability occur in the lower cervical spine, e.g., from C4 to C7. Using C2-C3 as the baseline is a more reliable and consistent in clinical application.

Therefore, self-comparison should be done on the flexion radiographs because in this position the abnormal flexibility will be more easily induced, helping to determine the injured segments. Further, the characteristics of minimal differences will provide more sensitive and reliable criteria to locate the abnormal segments. This analysis process should be useful for following up the changes in motion pattern in patients with degenerative changes, radiculopathy, and trauma; such an analysis is underway. Patterns and statistically significant differences will be determined between patients and the healthy population that can aid in the diagnoses of a defined patient population.

In this study, the authors also focused on the characteristics of flexion radiographs for the following reasons. In clinical practice, flexion radiographs can be used to determine the segments of abnormal motion. The data in this study can be used for these comparisons. The application of extension radiographs has some limitations because, even in normal spines, the lumbar and cervical spine could be slightly retrolisthetic in extension posture. 15 The locking of the facet joint in extension also could mask the abnormal motion. Usually, the abnormal motion includes flexion and extension instability. Hopefully, even the extension instability could be determined from the changes of either angulation or translation in flexion position. Further clinical studies are needed to test this.

**Conclusion**

From extension to flexion, the intervertebral angular displacement changed from lordotic to slightly kyphotic (almost neutral), and translation changed from retrolisthetic to slightly antelisthetic (almost zero displacement). When the intervertebral differences in flexion position and the levels and frequency distribution are considered, the normal behavior of cervical motion can be depicted more clearly.

**Key Points**

* Analyzing the sagittal dynamic motion in the cervical spine from extension to flexion, the intervertebral angulation changed from lordosis with different degrees to be nearly parallel, and the intervertebral translation changed from slightly retrolisthetic to zero displacement.
* Using C2-C3 as a baseline to calculate the intervertebral differences of angular displacement and translation in flexion radiographs gives reliable values for defining normal flexibility, that is, nearly all the intervertebral differences of angular displacement were less than 7°, and those of translation were less than 0.6 mm.
References