Age-related and degenerative changes in the osseous anatomy, alignment, and range of motion of the cervical spine: a comparative study of radiographic data from 1016 patients with cervical spondylotic myelopathy and 1230 asymptomatic subjects

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KEY POINTS

- This study investigated cervical spine morphometry, alignment, and range of motion (ROM) in members of each sex in each decade of life, and attempted to elucidate these age-related changes and differences in the radiographic results of cervical spine imaging between a large series of cervical spondylotic myelopathy (CSM) patients and healthy subjects.
- Cervical lordosis in the neutral position increased with aging in both CSM patients and asymptomatic subjects. CSM patients showed a smaller lordotic angle than asymptomatic subjects.
- The total ROM decreased with increasing age in both groups. The total ROM of CSM patients was significantly smaller than that of asymptomatic subjects.
- Although the flexion ROM did not change with aging in either group, the extension ROM decreased gradually in both groups.

Introduction

Degenerative changes in the cervical spine are commonly observed in healthy subjects.[1,2] Cervical degenerative disease is one of the most prevalent and increasingly observed neurological disorders in the geriatric population.[3,4] Cervical spondylotic myelopathy (CSM) is a neurological disorder caused by narrowing of the spinal canal due to degenerative changes in the cervical spine.[5] Given the prevalence of degeneration in the aging population, a detailed clinical history and physical examination are important. The findings of image would be correlated with these results. Plain radiographic evaluation which includes lateral and lateral flexion-extension views is an essential first step. And it remains the gold standard for the diagnosis of cervical spine disease.[6-8] Several emphases on assessing for alignment and abnormal instability are evaluated by radiographs. Previous studies have been performed using plain radiographs to elucidate the normal morphology and kinematic behavior of the cervical spine.[9-12]

There have been few reports concerning the anatomic morphometry, alignment, and range of motion (ROM) of the degenerative cervical spine and age-related changes of these parameters.[2] However, to the best of our knowledge, there are no reports evaluating the differences in radiographic results of cervical spine imaging between a large series of CSM patients and healthy subjects. We therefore conducted a comparative study of the radiographic data from a large series of CSM patients and healthy subjects. This study aimed to establish cervical spine morphometry, alignment, and ROM, and to clarify the impact of age-related and degenerative changes.

Materials and Methods

Study Population

CSM patients

Between April 1995 and March 2011, 1596 consecutive patients underwent modified double-door laminoplasty. All the patients presented with symptoms of myelopathy. Magnetic resonance imaging (MRI) and myelography findings were consistent with myelopathy secondary to multisegmental cervical spondylotic stenosis. Each patient had myelopathy confirmed by a physical examination, and cord compression was present only between the C2/C3 and C7/T1 disc levels. Exclusion criteria included the following: 1) ossification of the posterior longitudinal ligament; 2) history of rheumatoid arthritis, cerebral palsy, or tumors; 3) injuries; 4) destructive spondyloarthritis caused by hemodialysis; 5) previous cervical surgery; 6) spinal fusion with instrumentation; 7) thoracic spondylotic myelopathy; and 8) lumbar spinal canal stenosis. Of these, 1025 patients were followed for more than 12 months after surgery. These patients included 642 males and 383 females; the mean age was 64.4 years (range, 23–93 years). Finally, 1016 patients, excluding those in the third and tenth decade of life, were prospectively enrolled as CSM patients in this study. CSM patients (638 male and 378 female, mean age: 62.2 years) were classified based on each decade of life between the fourth and ninth decade (Table 1). All radiographs were performed before surgery in CSM patients.

Asymptomatic subjects

Between February 2006 and February 2008, 1230 healthy volunteers (616 male and 614 female) were prospectively enrolled as asymptomatic subjects in this study. The subjects with a history of brain or spinal surgery, comorbid neurologic diseases, such as cerebral infarction or neuropathy, symptoms related to sensory or motor disorders (e.g., numbness, clumsiness, motor weakness, and gait disturbances), or the presence of severe neck pain were excluded. The

exclusion criteria also included pregnant women and individuals who received worker's compensation or presented with symptoms after a motor vehicle accident. There were at least 100 males and 100 females in each decade of life between the third and eighth decades. Table 1 shows the age and gender of the subjects. The Institutional Review Board approved this project and we obtained written informed consent from CSM patients and asymptomatic subjects before examination.

Radiographic Evaluations

Lateral radiographs of the cervical spine in neutral, flexion, and extension positions with a distance of 1.5 m between the X-ray tube and the film were taken in all the subjects (Figure 1). Lateral radiographs were taken with the subject standing and facing straight ahead. Cervical sagittal alignment on the neutral and flexion-extension views were measured by the Cobb method at C2–7. The lordotic angle between C2 and C7 was defined, with positive and negative lordotic angles indicating cervical lordosis and kyphosis, respectively. Flexion and extension radiographs were performed with the neck in maximum flexion and extension positions, respectively. Angles created by a line parallel to the inferior aspect of the C2 vertebral body and a line parallel to that of the C7 vertebral body were measured on flexion and extension lateral radiographs. All images were transferred to the computer as DICOM data. Each parameter was measured using imaging software (Osiris4; Icestar Media Ltd, Essex, UK). In invisible case of the inferior aspect of the C7 vertebral body, we changed resolution and substituted with superior end plate of the C7 vertebral body to measure. The ROM was assessed by measuring the difference in alignment between flexion and extension.

Statistical Analysis

Data were analyzed using SPSS statistical software (version 18.0; SPSS, Inc., Chicago, IL, USA). All values are expressed as mean ± standard deviation. Nonparametric analysis using Mann-Whitney U test was used for analyzing the differences between the two groups and the Kruskal-Wallis test followed by the Mann-Whitney U test for analyzing the differences among more than three groups. A *P* value of <0.05 was considered statistically significant.

Results

In CSM patients, the C2–7 alignment was 11.4 ± 9.8 [mean ± standard deviation (SD)] degrees in lordosis and the total ROM was 39.4 ± 10.9 degrees. The C2–7 lordotic angle was 4.9 ± 11.3 degrees in patients in their fourth decade and 13.3 ± 9.2 and degrees in patients in their ninth decade (Table 2). The total ROM was 41.6 ± 14.3 degrees in patients in their fourth decade and 35.2 ± 9.4 degrees in patients in their ninth decade (Table 2).

In asymptomatic subjects, the C2–7 alignment was 13.9 ± 12.3 degrees in lordosis and the total ROM was 55.3 ± 16.0 degrees. The C2–7 lordotic angle was 8.0 ± 11.8 degrees in the third decade and 19.7 ± 11.3 degrees in the eighth decade (Table 2). The total ROM was 67.7 ± 17.0 degrees in the third decade and 45.0 ± 12.5 degrees in the eighth decade (Table 2).

Cervical lordosis in the neutral position increased gradually with age in both groups (Figure 2). CSM patients showed significantly smaller lordotic angles than asymptomatic subjects in each decade (Table 3).

The total ROM decreased with increasing age in both groups (Figure 3). The total ROM of females was significantly larger than that of males (Table 3). The total ROM of CSM patients was significantly smaller than that of asymptomatic subjects (Table 3). The flexion ROM did not

markedly change with aging in either group (Figure 4). There was no significant difference in the flexion ROM between males and females between the two groups except eighth decade of asymptomatic subjects. (Table 3). However, the extension ROM decreased gradually in both groups (Figure 5). The extension ROM of CSM patients was significantly smaller than that of asymptomatic subjects (Table 3).

Discussion

Degenerative diseases of the spine, such as CSM, are increasing among the geriatric population, and surgical treatment of CSM is becoming more common.[13,14] This study investigated cervical spine morphometry, alignment, and ROM in members of each sex in each decade of life, and attempted to elucidate these age-related changes and differences in the radiographic results of cervical spine imaging between a large series of CSM patients and healthy subjects. Cervical lordosis in the neutral position increased with aging in both CSM patients and asymptomatic subjects. CSM patients showed a smaller lordotic angle than asymptomatic subjects. The total ROM decreased with increasing age in both groups. The total ROM of CSM patients was significantly smaller than that of asymptomatic subjects. Although the flexion ROM did not change with aging in either group, the extension ROM decreased gradually in both groups.

Cervical lordosis observed in the neutral position increases with aging, in general.[2,10-12] This is likely due to the degenerative changes that occur in a sagittal plane. The thoracic kyphosis angle also increases with age.[15] Generally, the elderly exhibit greater thoracic kyphosis, therefore they develop greater compensatory lordosis of the cervical spine with increasing age.[12] Imagama reported that the lumbar lordosis angle and spinal ROM decrease and spinal inclination

increases in older subjects.[15] In their study, the thoracic kyphosis angle also tended to worsen gradually with aging.[15]

In the present study, we found that cervical lordosis in the neutral position increased gradually with age in both CSM patients and asymptomatic subjects. Furthermore, CSM patients showed smaller lordotic angles with increasing age than asymptomatic subjects. It is believed that the decrease in cervical lordosis observed with degeneration is caused by degenerative intervertebral discs and that the posture to avoid neurological symptoms induces neck extension.[4,16] In our study, cervical lordosis increased gradually with age-related changes, whereas cervical lordosis decreased as a result of spondylotic degenerative changes.

The total ROM decreased linearly with increasing age. In the literature, there is general agreement that the ROM of the cervical spine decreases with increasing age.[2,17] Lind first described that flexion movements are less affected by age than extension movements of the cervical spine.[18] The accurate mechanism of this phenomenon has not been explained exactly. The decrease in ROM might be caused by the degeneration of intervertebral discs and the contraction of facet joints. Another reported potential cause for reduced cervical ROM is atrophy and dysfunction of paraspinal muscles. Spinal ROM and spinal sagittal alignment tend to worsen with aging.[16]

The present study also demonstrated that the total ROM decreased with increasing age in both CSM patients and asymptomatic subjects. The total ROM of females was larger than that of males. The total ROM of CSM patients was significantly smaller than that of asymptomatic subjects. Therefore, symptomatic patients may have limited ROM because it produces pain or neurologic compression. It was speculated that neurologic symptoms in the CSM patients affected cervical ROM. Age-related changes and spondylotic degenerative changes reduced

ROM. The flexion ROM was not affected by age-related or degenerative changes, and age-related and degenerative changes influenced the decrease observed in the extension ROM. Most of the decreases observed in ROM depended on the decrease in the extension ROM.

The current study has some limitations. First, one limitation of this study involves the possibility of measurement errors in our method of measuring cervical alignment and ROM. Cervical movement is multidirectional, but in our study, radiographical analysis of movement in only 1 plane was measured. Multi-directional movements, including rotational motion and lateral bending were not considered.[2] Second, to achieve the same vertebral position in relation to the X-ray beam in different motion positions is difficult. Third, because the number of specific measurements and the number of subjects were very large, measurement was performed only once. However, the measurements of CSM patients were carried out by an experienced spinal surgeon and the measurements of asymptomatic subjects were carried out by well-experienced radiology technologists with extensive knowledge of cervical osseous anatomy. Our data set was sufficiently large for most evaluation.[2] Fourth, a distance of 1.5 m between the X-ray tube was used and the film without correction for magnification. We did not evaluate the measurement of distance and only measured the angle. Then, comparison with other studies using a distance of 1.8 m, should not require any adjustments. Fifth, all data in this study were derived only from Japanese patients and Japanese volunteers, majority of whom belong to a single race. It might be difficult to apply these findings to other races in a similar fashion for this reason. However Japanese have most advanced aging society and these data are useful to help people of other races, who would prepare for an aged society, to understand age-related change[2]. The strength of this study is that it includes the largest number of CSM patients and asymptomatic subjects in the literature on this subject.

Conclusion

We established the age-related and degenerative changes in the cervical spine, as well as the alignment and ROM in each decade of age, between CSM patients and asymptomatic subjects. Cervical lordosis increased with age in both groups. CSM patients showed smaller lordotic angles than asymptomatic subjects. The total ROM decreased with increasing age in both groups. The total ROM of CSM patients was significantly smaller than that of asymptomatic subjects. Although the flexion ROM did not change with aging in either group, the extension ROM decreased gradually in both groups.

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Table 1.
Demographics of subjects at present study

CSM patients							
	30’	40’	50’	60’	70’	80’	ALL
Male	13	69	158	210	152	34	636
Female	5	18	70	109	135	43	380
Total	18	87	228	319	287	77	1016
Asymptomatic subjects							
	20’	30’	40’	50’	60’	70’	ALL
Male	103	105	100	105	101	102	616
Female	102	102	100	102	106	102	614
Total	205	207	200	207	207	204	1230

Table 2.
Demographics of subjects at present study

	Lordotic angle	Total ROM	Flexion ROM	Extension ROM
CSM patients Male				
30’	4.7±9.5	40.2±15.7	22.1±8.4	18.1±12.9
40’	5.6±10.1	39.1±12.0	24.4±9.6	14.7±8.9
50’	9.6±8.4	40.1±10.2	26.8±7.8	13.3±7.7
60’	11.7±9.6	38.5±10.4	27.0±8.4	11.4±8.0
70’	13.3±9.6	37.2±10.3	26.4±8.4	10.8±6.8
80’	11.7±8.5	32.9±10.7	23.2±7.9	9.7±7.8
CSM patients Female				
30’	5.6±16.4	45.4±10.2	32.4±14.0	13.0±10.7
40’	8.6±8.5	44.1±14.8	27.2±6.5	16.8±11.9
50’	10.6±8.5	42.8±11.6	27.4±9.1	15.3±7.5
60’	11.6±9.2	42.5±11.1	26.9±9.3	15.6±8.0
70’	14.3±11.3	40.2±10.5	27.3±9.3	12.9±7.7
80’	14.6±9.5	37.0±8.0	25.8±8.8	11.2±7.0
Asymptomatic subjects Male				
20’	11.0±11.4	64.1±16.1	29.7±11.0	34.3±14.5
30’	10.6±10.8	61.8±12.6	28.3±10.1	33.6±10.7
40’	14.1±10.3	53.1±11.2	27.6±8.2	25.5±11.6
50’	18.3±11.7	48.5±11.8	27.4±8.9	21.2±9.8
60’	18.4±11.5	41.8±12.7	25.5±9.5	16.2±9.4
70’	20.7±12.0	41.7±9.7	27.2±9.1	14.6±7.9
Asymptomatic subjects Female				
20’	5.3±11.4	71.3±17.3	29.0±10.7	42.2±14.5
30’	6.6±10.7	65.2±14.8	26.7±9.3	38.5±13.7
40’	9.9±11.2	59.7±14.4	26.9±9.7	32.9±12.3
50’	14.9±12.1	54.8±13.0	25.1±9.6	29.6±12.0
60’	17.1±10.8	53.3±10.8	26.5±8.3	26.8±8.9
70’	18.4±10.3	48.5±13.8	23.5±8.9	24.8±11.1

Table 3.
Demographics of each parameters and Comparisons of each subjects at present study

	CSM Male	CSM Female	Asymp Male	Asymp Female	P value
Lordotic angle					
20’			11.0±11.4	5.3±11.4	0.0009
30’	4.7±9.5	5.6±16.4	10.6±10.8	6.6±10.7	0.0223
40’	5.6±10.1	8.6±8.5	14.1±10.3	9.9±11.2	<0.0001
50’	9.6±8.4	10.6±8.5	18.3±11.7	14.9±12.1	<0.0001
60’	11.7±9.6	11.6±9.2	18.4±11.5	17.1±10.8	<0.0001
70’	13.3±9.6	14.3±11.3	20.7±12.0	18.4±10.3	<0.0001
80’	11.7±8.5	14.6±9.5			0.2120
Total ROM					
20’			64.1±16.1	71.3±17.3	0.0007
30’	40.2±15.7	45.4±10.2	61.8±12.6	65.2±14.8	<0.0001
40’	39.1±12.0	44.1±14.8	53.1±11.2	59.7±14.4	<0.0001
50’	40.1±10.2	42.8±11.6	48.5±11.8	54.8±13.0	<0.0001
60’	38.5±10.4	42.5±11.1	41.8±12.7	53.3±10.8	<0.0001
70’	37.2±10.3	40.2±10.5	41.7±9.7	48.5±13.8	<0.0001
80’	32.9±10.7	37.0±8.0			0.0458
Flexion ROM					
20’			29.7±11.0	29.0±10.7	0.7332
30’	22.1±8.4	32.4±14.0	28.3±10.1	26.7±9.3	0.0847
40’	24.4±9.6	27.2±6.5	27.6±8.2	26.9±9.7	0.0789
50’	26.8±7.8	27.4±9.1	27.4±8.9	25.1±9.6	0.2179
60’	27.0±8.4	26.9±9.3	25.5±9.5	26.5±8.3	0.5775
70’	26.4±8.4	27.3±9.3	27.2±9.1	23.5±8.9	0.0070
80’	23.2±7.9	25.8±8.8			0.2740
Extension ROM					
20’			34.3±14.5	42.2±14.5	0.0001
30’	18.1±12.9	13.0±10.7	33.6±10.7	38.5±13.7	<0.0001
40’	14.7±8.9	16.8±11.9	25.5±11.6	32.9±12.3	<0.0001
50’	13.3±7.7	15.3±7.5	21.2±9.8	29.6±12.0	<0.0001
60’	11.4±8.0	15.6±8.0	16.2±9.4	26.8±8.9	<0.0001
70’	10.8±6.8	12.9±7.7	14.6±7.9	24.8±11.1	<0.0001
80’	9.7±7.8	11.2±7.0			0.2518

Asymp: Asymptomatic subjects

Figure legends

Figure 1.
Cervical sagittal alignment in the neutral and flexion-extension view

Figure 2.
Cervical sagittal alignment (C2–7 lordotic angle)
Error bar: Standard deviation

Figure 3.
Cervical total ROM in the flexion-extension
Error bar: Standard deviation

Figure 4.
Cervical flexion ROM
Error bar: Standard deviation

Figure 5.
Cervical extension ROM
Error bar: Standard deviation