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ORIGINAL ARTICLE

Age-related changes in osseous anatomy, alignment, and range of motion of the cervical spine. Part I: Radiographic data from over 1,200 asymptomatic subjects

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Abstract
Purpose This study aimed to establish radiographic standard values for cervical spine morphometry, alignment, and range of motion (ROM) in both male and female in each decade of life between the 3rd and 8th and to elucidate these age-related changes.
Methods A total of 1,230 asymptomatic volunteers underwent anteroposterior (AP), lateral, flexion, and extension radiography of the cervical spine. There were at least 100 men and 100 women in each decade of life between the 3rd and 8th. AP diameter of the spinal canal, vertebral body, and disc were measured at each level from the 2nd to 7th cervical vertebra (C2–C7). C2–C7 sagittal alignment and ROM during flexion and extension were calculated using a computer digitizer.
Results The AP diameter of the spinal canal was 15.8 ± 1.5 [mean ± standard deviation (SD)] mm at the mid-C5 level, and 15.5 ± 2.0 mm at the C5/6 disc level. The disc height was 5.8 ± 1.3 mm at the C5/6 level, which was the minimum height, and the maximum height was at the C6/7 level. Both the AP diameter of the spinal canal and disc height decreased gradually with increasing age. The C2–C7 sagittal alignment and total ROM were 13.9 ± 12.3° in lordosis and 55.3 ± 16.0°, respectively. The C2–C7 lordotic angle was 8.0 ± 11.8° in the 3rd decade and increased to 19.7 ± 11.3 in the 8th decade, whereas the C2–C7 ROM was 67.7 ± 17.0° in the 3rd decade and decreased to 45.0 ± 12.5 in the 8th decade. The extension ROM decreased more than the flexion ROM, and lordotic alignment progressed with increasing age. There was a significant difference in C2–C7 alignment and ROM between men and women.
Conclusions The standard values and age-related changes in cervical anatomy, alignment, and ROM for males and females in each decade between the 3rd and 8th were established. Cervical lordosis in the neutral position develops with aging, while extension ROM decreases gradually. These data will be useful as normal values for the sake of comparison in clinical practice.

Keywords Cervical spine · Radiography · Osseous anatomy · Standard value · Age-related

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Introduction

Degenerative changes in the cervical spine become more common with time and may also present as normal aging variations [9]. Cervical degenerative disease is one of the most common neurological disorders that are being increasingly observed in the geriatric population. The development of this disease may be attributed to cervical spondylosis, disc herniation, and so on. Many patients exhibit various clinical features including neck pain, radiculopathy and myelopathy. Given the prevalence of degeneration in the aging population, a detailed clinical history and physical examination are crucial. Imaging findings can then be correlated with these results. There is no doubt that computed tomography and magnetic resonance imaging have brought about a revolution in the diagnosis of cervical disorders. However, plain radiographic evaluation, which includes anteroposterior (AP), lateral and lateral flexion–extension views, is an essential first step and remains the gold standard for diagnosis of cervical spine disease. Radiographs are evaluated with an emphasis on alignment, disc space height, presence or absence of spurring, diameter of the spinal canal, and abnormal instability. Several studies have been performed using plain radiographs to establish normal morphology and kinematic behavior of the cervical spine [2, 3, 7, 10]. However, there have been few studies using a large cohort with an even age and gender distribution. This study investigated cervical spine morphometry, alignment, and range of motion (ROM) in members of each sex in each decade of life between the 3rd (20s) and 8th (70s), and attempted to elucidate these age-related changes using data from radiographs of over 1,200 healthy subjects.

Materials and methods

A total of 1,230 healthy Japanese volunteers (616 men and 614 women) were enrolled in this study. The exclusion criteria included a history of brain or spinal surgery, comorbid neurologic disease such as cerebral infarction or neuropathy, symptoms related to sensory or motor disorders (numbness, clumsiness, motor weakness, and gait disturbances) or having severe neck pain. Pregnant women and individuals who received worker's compensation or presented with symptoms after a motor vehicle accident were also excluded. At least 100 men and 100 women belonged to each decade of life between the 3rd and 8th.

AP, lateral (neutral), flexion, and extension X-rays of the cervical spine were taken with a distance of 1.5 m between the X-ray tube and the film in all the subjects. Lateral (neutral) X-ray was taken with the subject standing and facing straightforwardly. Flexion and extension X-rays were taken with the neck in maximum flexion and extension position. The AP diameter of the spinal canal was calculated at each disc level from C2/3 to C7/T1 and each mid-vertebral level from C2 to C7. The heights of the vertebral body and discs were also calculated at each level. The alignment from C2 to C7 was measured in neutral, flexion, and extension positions (Fig. 1). Total, flexion, and extension ROMs were also calculated.

All images were transferred to the computer as DICOM data. Each parameter was measured by experienced radiation technologists using imaging software (Osiris4; Icestar Media Ltd, Essex, UK).

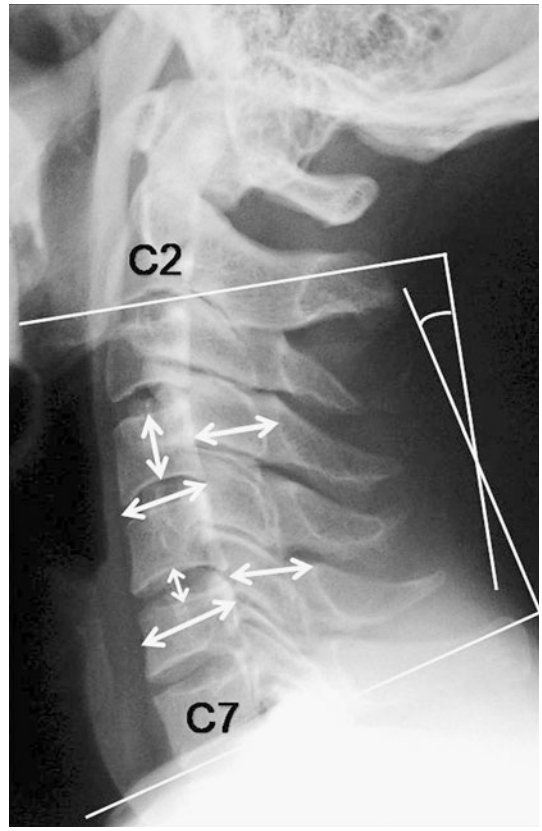

Fig. 1 Measurement of each parameter in lateral (neutral) X-ray

Statistical analysis

A standard StatView (SAS Institute, Cary, NC, USA) software package was used for statistical analysis. Nonparametric analysis using the Mann–Whitney *U* test was performed for analyzing differences between two groups, and the Kruskal–Wallis test followed by the Mann–Whitney *U* test for analyzing differences among three groups. Repeated-measures analyses of variance within the same group were performed using the Wilcoxon test. A *p* value of <0.05 was considered statistically significant.

Results

Average height and weight [mean ± standard deviation (SD)] of all subjects was 162.2 ± 9.3 cm/59.8 ± 11.3 kg, whereas the average calculated separately for male and female patients was 168.8 ± 6.8 cm/66.4 ± 10.3 kg and 155.5 ± 6.8 cm/53.1 ± 7.8 kg, respectively.

The AP diameters of the spinal canal at each disc level are shown in Table 1, whereas those at each mid-vertebral level are shown in Table 2. The diameter at each disc level was minimum at the C5/6 and maximum at the C2/3 level, whereas that at each mid-vertebral level was minimum at

Table 1 AP diameter of spinal canal at each disc level in neutral position

	C2/3	C3/4	C4/5	C5/6	C6/7	C7/T1
All	17.7 ± 1.9	15.9 ± 1.8	15.5 ± 1.8	15.5 ± 2.0	15.9 ± 1.9	16.2 ± 1.6
Male	18.2 ± 2.0	16.3 ± 1.9	15.9 ± 1.9	15.9 ± 2.1	16.3 ± 2.0	16.6 ± 1.7
Female	17.2 ± 1.7	15.6 ± 1.7	15.2 ± 1.7	15.1 ± 1.8	15.6 ± 1.7	15.9 ± 1.4
Male						
20 M	18.2 ± 1.9	16.2 ± 1.7	15.8 ± 1.8	16.0 ± 1.8	16.3 ± 1.8	16.6 ± 1.5
30 M	18.8 ± 1.9	16.6 ± 1.8	16.2 ± 1.7	16.3 ± 1.8	16.8 ± 1.7	17.1 ± 1.6
40 M	18.2 ± 2.0	16.6 ± 1.7	16.3 ± 1.8	16.2 ± 2.1	16.8 ± 1.8	17.0 ± 1.7
50 M	18.3 ± 1.9	16.4 ± 1.9	16.1 ± 1.9	15.9 ± 2.2	16.4 ± 2.1	16.7 ± 1.6
60 M	17.9 ± 2.0	16.2 ± 2.0	15.8 ± 1.8	15.8 ± 2.3	16.0 ± 2.2	16.3 ± 1.8
70 M	17.5 ± 1.8	15.6 ± 2.1	15.2 ± 2.0	15.0 ± 2.2	15.4 ± 2.0	15.9 ± 1.5
Female						
20 F	17.8 ± 1.5	15.9 ± 1.4	15.4 ± 1.6	15.5 ± 1.6	15.8 ± 1.6	15.9 ± 1.6
30 F	17.4 ± 1.6	15.6 ± 1.6	15.2 ± 1.4	15.2 ± 1.5	15.8 ± 1.6	16.0 ± 1.3
40 F	17.5 ± 1.5	15.8 ± 1.5	15.4 ± 1.5	15.2 ± 1.8	15.9 ± 1.6	16.2 ± 1.3
50 F	17.3 ± 2.0	15.7 ± 1.9	15.4 ± 2.0	15.3 ± 1.9	15.8 ± 1.6	16.1 ± 1.4
60 F	16.7 ± 1.7	15.2 ± 1.7	14.9 ± 1.8	14.7 ± 1.9	15.1 ± 1.8	15.5 ± 1.3
70 F	16.6 ± 1.8	15.1 ± 1.9	14.8 ± 1.8	14.4 ± 2.1	14.9 ± 1.9	15.6 ± 1.5

The values are mean ± SD (mm)

Table 2 AP diameter of spinal canal at each mid-vertebral level in neutral position

	C2	C3	C4	C5	C6	C7
All	18.7 ± 1.9	16.0 ± 1.6	15.5 ± 1.5	15.8 ± 1.5	16.2 ± 1.5	16.2 ± 1.4
Male	19.2 ± 1.9	16.4 ± 1.6	15.8 ± 1.5	16.2 ± 1.5	16.7 ± 1.5	16.7 ± 1.4
Female	18.2 ± 1.7	15.7 ± 1.5	15.2 ± 1.5	15.4 ± 1.4	15.8 ± 1.4	15.8 ± 1.3
Male						
20 M	19.5 ± 2.0	16.7 ± 1.7	16.0 ± 1.6	16.3 ± 1.5	16.7 ± 1.5	16.7 ± 1.4
30 M	19.9 ± 1.9	16.8 ± 1.6	16.2 ± 1.5	16.5 ± 1.4	17.0 ± 1.4	17.0 ± 1.3
40 M	19.2 ± 1.9	16.2 ± 1.5	15.9 ± 1.3	16.5 ± 1.3	16.9 ± 1.3	17.0 ± 1.4
50 M	19.1 ± 1.6	16.3 ± 1.6	15.8 ± 1.6	16.1 ± 1.5	16.5 ± 1.5	16.6 ± 1.3
60 M	18.8 ± 2.1	16.2 ± 1.7	15.6 ± 1.6	16.1 ± 1.5	16.5 ± 1.5	16.4 ± 1.4
70 M	18.4 ± 1.8	16.1 ± 1.5	15.5 ± 1.5	15.7 ± 1.4	16.3 ± 1.5	16.2 ± 1.5
Female						
20 F	18.9 ± 1.6	16.1 ± 1.3	15.5 ± 1.4	15.7 ± 1.3	16.1 ± 1.3	16.0 ± 1.3
30 F	18.6 ± 1.6	15.9 ± 1.4	15.4 ± 1.4	15.7 ± 1.3	16.1 ± 1.3	16.0 ± 1.2
40 F	18.7 ± 1.6	16.0 ± 1.5	15.4 ± 1.4	15.6 ± 1.4	16.0 ± 1.3	16.1 ± 1.2
50 F	18.3 ± 1.7	15.7 ± 1.6	15.3 ± 1.5	15.6 ± 1.6	16.1 ± 1.2	16.0 ± 1.3
60 F	17.6 ± 1.7	15.1 ± 1.4	14.7 ± 1.4	14.9 ± 1.3	15.3 ± 1.3	15.3 ± 1.2
70 F	17.4 ± 1.5	15.3 ± 1.5	14.6 ± 1.4	15.0 ± 1.5	15.3 ± 1.5	15.4 ± 1.3

The values are mean ± SD (mm)

the C4 and maximum at the C2 level. The vertebral body heights at the AP center of each disc are shown in Table 3. The shortest was at the C6 and longest at the C7 level. Disc height is shown in Table 4, which was minimum at the C5/6 and maximum at the C6/7 level. The AP diameter of the spinal canal, vertebral height, and disc height all gradually decreased with increasing age. There was also a significant difference between males and females in all these parameters.

The C2–C7 sagittal alignment and total ROM are shown in Table 5 and plotted in Figs. 2 and 3. The C2–C7 average sagittal alignment and total ROM were 13.9 ± 12.3° in lordosis and 55.3 ± 16.0°, respectively. The C2–C7 lordotic angle was 8.0 ± 11.8° in subjects in the 3rd decade, and increased to 19.7 ± 11.3° in subjects in the 8th decade. The C2–C7 ROM was 67.7 ± 17.0° in subjects in the 3rd decade, and decreased to 45.0 ± 12.5 in subjects in the 8th decade. The extension ROM decreased more than

Table 3 Vertebral body height in the center at each level

	C3	C4	C5	C6	C7
All	13.4 ± 1.7	13.0 ± 1.6	12.8 ± 1.5	12.6 ± 1.5	14.0 ± 1.6
Male	14.4 ± 1.5	13.9 ± 1.5	13.7 ± 1.4	13.4 ± 1.4	14.9 ± 1.5
Female	12.4 ± 1.2	12.1 ± 1.2	12.0 ± 1.1	11.9 ± 1.2	13.1 ± 1.3
Male					
20 M	14.9 ± 1.4	14.3 ± 1.5	14.1 ± 1.3	13.7 ± 1.3	15.5 ± 1.4
30 M	14.5 ± 1.4	14.0 ± 1.4	13.8 ± 1.3	13.6 ± 1.3	15.1 ± 1.4
40 M	14.7 ± 1.4	14.2 ± 1.5	13.9 ± 1.5	13.7 ± 1.3	15.3 ± 1.2
50 M	14.6 ± 1.4	14.2 ± 1.4	13.8 ± 1.4	13.4 ± 1.2	14.8 ± 1.5
60 M	14.2 ± 1.4	13.7 ± 1.3	13.5 ± 1.4	13.2 ± 1.4	14.6 ± 1.4
70 M	13.5 ± 1.4	13.1 ± 1.3	12.9 ± 1.4	12.8 ± 1.3	14.1 ± 1.5
Female					
20 F	12.9 ± 1.1	12.4 ± 1.1	12.4 ± 1.2	12.5 ± 1.2	13.6 ± 1.3
30 F	12.6 ± 1.1	12.4 ± 1.0	12.4 ± 1.1	12.3 ± 1.1	13.7 ± 1.2
40 F	12.5 ± 1.1	12.2 ± 1.0	12.2 ± 1.0	12.2 ± 1.1	13.4 ± 1.2
50 F	12.5 ± 1.1	12.2 ± 1.1	12.0 ± 1.0	11.8 ± 0.9	13.1 ± 1.1
60 F	12.2 ± 1.1	11.9 ± 1.2	11.7 ± 1.0	11.4 ± 1.1	12.7 ± 1.2
70 F	11.7 ± 1.2	11.4 ± 1.2	11.3 ± 1.2	11.2 ± 1.0	12.3 ± 1.2

The values are mean ± SD (mm)

Table 4 Disc height in the center at each level

	C2/3	C3/4	C4/5	C5/6	C6/7	C7/T1
All	6.1 ± 1.0	6.2 ± 1.0	5.9 ± 1.0	5.8 ± 1.3	6.4 ± 1.4	5.9 ± 1.0
Male	6.4 ± 0.9	6.5 ± 1.0	6.2 ± 1.1	6.1 ± 1.3	6.6 ± 1.5	6.1 ± 1.1
Female	5.8 ± 0.9	5.9 ± 1.0	5.6 ± 0.9	5.4 ± 1.1	6.3 ± 1.2	5.7 ± 1.0
Male						
20 M	6.1 ± 1.0	6.4 ± 0.9	6.2 ± 0.8	6.5 ± 0.9	7.1 ± 1.0	6.0 ± 1.2
30 M	6.3 ± 0.9	6.7 ± 0.9	6.4 ± 1.0	6.5 ± 1.0	7.2 ± 1.0	6.1 ± 1.0
40 M	6.4 ± 0.9	6.5 ± 0.9	6.3 ± 0.8	6.3 ± 1.0	6.9 ± 1.1	6.0 ± 0.8
50 M	6.4 ± 0.9	6.5 ± 1.0	6.2 ± 0.9	6.0 ± 1.3	6.5 ± 1.5	6.3 ± 1.1
60 M	6.5 ± 1.0	6.7 ± 1.1	6.2 ± 1.3	5.7 ± 1.7	6.2 ± 1.9	6.2 ± 1.2
70 M	6.4 ± 0.9	6.2 ± 1.3	6.0 ± 1.5	5.5 ± 1.4	5.9 ± 1.8	6.2 ± 1.1
Female						
20 F	5.6 ± 0.9	5.7 ± 0.9	5.5 ± 0.7	5.8 ± 0.8	6.3 ± 0.8	5.4 ± 0.9
30 F	5.5 ± 0.8	5.9 ± 0.9	5.5 ± 0.8	5.8 ± 0.9	6.5 ± 0.9	5.5 ± 0.9
40 F	5.7 ± 0.9	5.9 ± 0.8	5.5 ± 0.8	5.4 ± 1.0	6.4 ± 1.0	5.5 ± 0.9
50 F	5.9 ± 0.8	6.0 ± 0.9	5.8 ± 0.9	5.4 ± 1.1	6.3 ± 1.2	5.7 ± 0.9
60 F	5.9 ± 1.0	6.1 ± 1.2	5.7 ± 1.1	5.4 ± 1.4	6.3 ± 1.5	5.8 ± 1.0
70 F	5.9 ± 1.1	6.0 ± 1.0	5.6 ± 1.0	4.9 ± 1.3	5.7 ± 1.7	6.0 ± 1.1

The values are mean ± SD (mm)

the flexion ROM with increasing age (Fig. 2). However, this decrease was compensated by an increase in C2–C7 lordotic alignment (Fig. 3). There was a significant difference in C2–C7 alignment and ROM between men and women (Figs. 2, 3). The number and ratio of subjects whose C2–C7 alignment in the neutral position was kyphotic are shown in Table 6. The ratio was higher in females and younger subjects.

Several abnormal findings were seen on the X-rays of the study subjects. These included congenital or acquired synostosis ($n = 14$), ossification of posterior longitudinal ligaments ($n = 5$) and C1/2 subluxation ($n = 1$).

Discussion

This study aimed to establish standard values for cervical spine morphometry, alignment, and ROM in healthy members of each sex in each decade of life between the 3rd and 8th, and to elucidate these age-related changes. Several

Table 5 Flexion, extension, total ROM and C2-7 alignment

	Flexion ROM	Extension ROM	Total ROM	C2-7 lordosis in neutral position
All	27.0 ± 9.7	28.3 ± 14.1	55.3 ± 16.0	13.9 ± 12.3
Male	27.6 ± 9.8	24.3 ± 13.2	51.9 ± 15.2	15.5 ± 12.2
Female	26.4 ± 9.6	32.4 ± 13.7	58.8 ± 16.1	12.3 ± 12.3
Male				
20 M	29.9 ± 11.1	34.0 ± 13.6	63.9 ± 15.6	10.8 ± 11.6
30 M	28.2 ± 10.4	33.4 ± 10.7	61.5 ± 12.7	10.7 ± 10.9
40 M	27.6 ± 8.3	25.5 ± 11.7	53.1 ± 11.3	14.1 ± 10.4
50 M	27.3 ± 9.6	21.5 ± 11.0	48.7 ± 12.0	18.4 ± 12.8
60 M	25.5 ± 9.5	16.2 ± 9.4	41.8 ± 12.7	18.4 ± 11.6
70 M	27.2 ± 9.1	14.7 ± 8.0	41.8 ± 9.0	20.7 ± 12.0
Female				
20 F	28.8 ± 10.8	42.6 ± 15.1	71.6 ± 17.5	5.2 ± 11.4
30 F	27.0 ± 9.5	38.4 ± 13.7	65.4 ± 14.7	7.0 ± 11.2
40 F	26.9 ± 9.8	32.9 ± 12.3	59.7 ± 14.4	9.9 ± 11.2
50 F	25.7 ± 9.6	29.3 ± 11.3	55.1 ± 12.8	15.7 ± 12.2
60 F	26.3 ± 8.4	26.7 ± 8.8	53.0 ± 10.9	16.9 ± 10.8
70 F	23.4 ± 8.9	24.6 ± 11.2	48.1 ± 14.0	18.7 ± 10.6

The values are mean ± SD (mm)

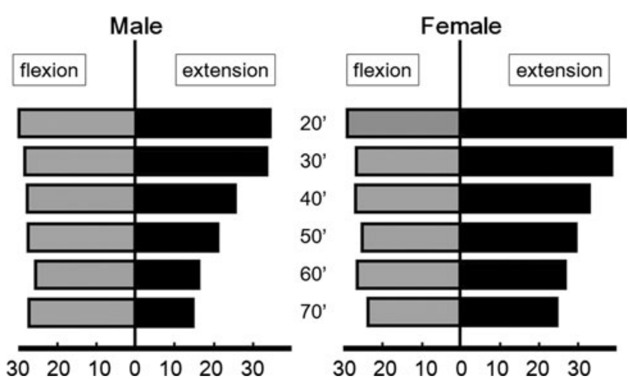

Fig. 2 Flexion, extension and total ROM in each sex and each decade

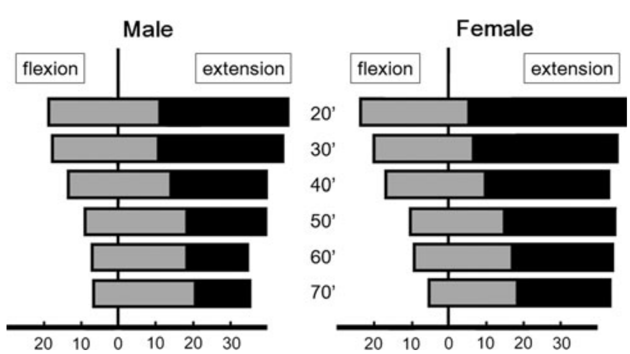

Fig. 3 Flexion, extension and total ROM in each sex and each decade adjusted by neutral sagittal alignment

parameters, i.e., the AP diameter of the spinal canal at each disc and vertebral level and the height of each vertebral body and disc were established in each sex in each decade,

Table 6 Number of kyphotic population and its ratio

	Total	Number	Ratio (%)
All	1,230	164	13.3
Male	616	60	9.7
Female	614	104	16.9
Male			
20 M	103	20	19.4
30 M	105	13	12.4
40 M	100	10	10.0
50 M	105	8	7.6
60 M	101	5	5.0
70 M	102	4	3.9
Female			
20 F	102	34	33.3
30 F	102	28	27.5
40 F	100	20	20.0
50 F	102	13	12.7
60 F	106	4	3.8
70 F	102	5	4.9

and are demonstrated in the Tables. Most of these parameters decreased gradually with increasing age. Degenerative changes occurred more at disc level than at mid-vertebral level. In the sagittal plane, cervical lordosis in the neutral position increased with age, especially in the 6th decade. Cervical lordosis increased more with age in females than in males. Total ROM also decreased linearly with increasing age. Most of the decreasing changes depended on the decrease in extension ROM. The axis of the total

ROM based on a neutral position did not change very much with age in males, but shifted to the extension direction in females (Fig. 3).

The influence of a developmentally narrow cervical canal on the pathogenesis of spondylotic myelopathy has been emphasized by several workers [1, 11]. It is well-known that subjects with all the radiological features of cervical spondylosis may be symptom free [9], while on the other hand, minimal or moderate radiological changes may induce myelopathy. This discrepancy between radiological changes and the presence of symptoms in cervical spondylosis is attributable mainly due to differences in the initial size of the cervical spinal canal [5, 8]. Observation of the sagittal diameter in cervical spondylosis, therefore, is an important aspect of radiographic examination. There are several comprehensive studies describing the sagittal diameter of the cervical canal in normal subjects [4, 10]. However, there has been few studies performed on a large sample of healthy volunteers of uniform age and gender.

The sagittal diameter of the cervical canal at the mid-C5 level was 16.2 $\pm$ 1.5 mm in males and 15.4 $\pm$ 1.4 mm in females, whereas that at the C5/6 disc level was 15.9 $\pm$ 2.1 mm in males and 15.1 $\pm$ 1.8 mm in females. Considering that the critical border is defined by the value given by average $-$2SD, the critical sagittal diameter of the cervical canal at the mid-C5 level was considered to be approximately 13.2 mm in males and 12.6 mm in females. If the sagittal diameter is $\leq$13 mm in males or $\leq$12 mm in females, the subject is considered to have a narrow spinal canal. These data are similar to those of previous reports [10]. Males had significantly larger diameters than females both at the mid-C5 level and at the C5/6 disc level (16.2/15.4 and 15.9/15.1 mm, respectively) ($p < 0.01$). Correcting the influence of physical constitution based on sex, the sagittal diameter was divided by the average height. The female value adjusted by height [168.8 (male)/155.5 (female)] was 16.7 mm at the mid-C5 level and 16.4 mm at the C5/6 level, respectively, indicating that these values are approximately 3% higher in females. This difference in the sagittal diameter of the spinal canal adjusted according to sex-related physical constitution explains why cervical myelopathy is more common in males [6, 12, 13].

There is general agreement in literature that ROM of the cervical spine decreases with increasing age [2]. Flexion movements were less affected by age than extension movements. This was first described in a report by Lind [7]. The precise mechanism of this phenomenon has not been explained. The present study demonstrated that the total ROM also decreased linearly with increasing age and most decreases depended on reduction of the extension ROM. The axis of the total ROM based on a neutral position did not change with age in males, but shifted toward the extension direction in females. As older females exhibit greater thoracic kyphosis than males in general [3], women should therefore develop greater compensatory lordosis of the cervical spine with increasing age.

This study had several limitations. First, the possibility of measurement errors. Second, the difficulty in achieving the same position of the vertebrae in relation to the X-ray beam in different positions of motion. Third, measurement was performed only once because the number of specific measurements and the number of subjects were very large. However, the measurements were carried out by well-experienced radiation technologists with extensive knowledge of cervical osseous anatomy. Fourth, we used a distance of 1.5 m between the X-ray tube and the film without correction for magnification. Therefore, comparison with other studies, which used a distance of 1.8 m (6 feet), would require some adjustments. Fifth, all data in this study were derived only from Japanese volunteers, majority of whom belong to a single race. For this reason, it might be difficult to apply these findings to other races in a similar fashion. However Japanese have most advanced aging society, these data should help people of other races to understand aging change.

Conclusion

Standard values and those age-related changes in cervical spine morphometry, alignment, and ROM were established from cervical X-ray data of 1,230 healthy subjects. The sagittal diameter (mm) of the cervical canal at the mid-C5 level was 16.2 $\pm$ 1.5 mm in males and 15.4 $\pm$ 1.4 mm in females. If the sagittal diameter was $\leq$13 mm in males or $\leq$12 mm in females, the subject was considered to have a narrow spinal canal. The extension ROM decreased more than the flexion ROM, and lordotic alignment increased with advancing age.

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Conflict of interest None.

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