Original Article

Changes of cervical spinal cord and cervical spinal canal with age in asymptomatic subjects

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Study design: Prospective study on magnetic resonance imaging (MRI) and radiographic findings of the cervical spine.

Objective: To elucidate the age-related changes of the cervical spinal cord and the cervical spinal canal and the relationship between the spinal cord and the spinal canal in asymptomatic subjects using MRI and radiography.

Setting: Tokyo, Japan.

Methods: The transverse area of the cervical spinal cord and the ratio of the anteroposterior diameter to the transverse diameter (RAPT) were investigated, using MRI in 229 asymptomatic subjects. The sagittal spinal canal diameter and anteroposterior diameter of the cervical vertebral body were also measured on plain lateral radiographs. The canal body ratio (CBR), which was defined as the diameter of the spinal canal divided by that of the vertebral body, was calculated.

Results: The transverse spinal cord area correlated negatively with age. RAPT did not correlate with age. The CBR correlated negatively with age. The correlation between spinal cord area and CBR was significant but weak and the correlation between RAPT and CBR was not significant.

Conclusion: The transverse area of the cervical spinal cord measured by MRI decreased with age, while RAPT remained unchanged. The bony spinal canal became narrower with age. The spinal cord area and the shapes of the spinal cord were independent from the spinal canal diameter in asymptomatic subjects. These facts should be considered when evaluating radiological findings in patients with cervical spinal disorders.

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Keywords: cervical spinal cord; cervical spinal canal; aging; asymptomatic subject; MR imaging; radiography

Introduction

In the treatment of cervical spinal disorders such as compressive myelopathy and spinal cord injury, the transverse area of the cervical spinal cord of the patient has been considered as an effective predictor of clinical outcomes. Several authors have reported that the decreased spinal cord area before decompressive surgery would indicate poor surgical outcomes.^{1–4} The evaluation of the spinal cord area should be made after its comparison with norms obtained from asymptomatic subjects of each age group, since it may change with aging just as the cerebrum decreases in size with aging in the elderly. The relationship between the spinal cord and the

spinal canal in asymptomatic subjects should also be considered in the treatment of cervical spinal disorders, because patients with a tight spinal canal are more susceptible to spinal cord damage. To date, however, few studies have been made that focused on age-related changes in the cervical spinal cord and cervical spinal canal. The recent development of MRI has made it possible to obtain clear images of the cervical spinal cord non-invasively, thereby making measurements of transverse spinal cord area more applicable to routine practice. This morphometric study was undertaken to clarify age-related changes in the cervical spinal cord and the cervical spinal canal using MRI and radiography in order to establish the basis for the morphometric evaluation of the patients with cervical spinal cord disorders.

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Materials and methods

Subjects

Two hundred and twenty-nine Japanese volunteers (118 males and 111 females), who had no past history of cervical spinal disease or trauma, and had no neck, shoulder or arm symptoms, were enrolled in this study. Informed consent was obtained from all subjects prior to their enrollment. The volunteers were recruited via oral advertisement by members of the study team.⁵ The ages of the subjects were uniformly distributed within a range of 11 to 72 years, and the number of males or females in each decade from teenagers to more than 60 years of age ranged from 15 to 20.

MR imaging

All subjects underwent MRI of the cervical spine using a 0.5 Tesla scanner with a surface neck coil (Resona, Yokogawa medical system, Tokyo). T1 weighted axial images were obtained using a spin echo sequence (TE; 500, TR; 25, FOV; 22 cm, slice thickness; 5 mm, NEX; 2). The slices were made at the mid-vertebral body levels from C3 to C6 as well as at the intervertebral levels from C3–4 to C5–6. The slice planes were set parallel to each intervertebral disc space. Hard copies of the MR images were photographed with a digital camera (Nikon E2N, Tokyo, matrix size 1,300,000), and the images were analyzed on a personal computer (Aptiva H65, IBM Japan, Tokyo) using custom-made measurement software for which accuracy had been proven to be high by our preliminary tests. The transverse area and anteroposterior and transverse diameters of the spinal cord were measured, and the ratio of an anteroposterior to transverse diameters of the spinal cord was calculated (RAPT) (Figure 1). All measurements were performed three times by one of the investigators (M Ishikawa) and the data were averaged.

Figure 1 Measurements of the spinal cord. Anteroposterior diameter (mm) (A). Transverse diameter (mm) (B). Spinal cord area (mm²) (C). RAPT (%): A/B × 100

Radiography

All subjects also underwent lateral radiograph with their neck in the neutral position. They were told to look straight ahead in the relaxed position by an X-ray technician. The focus-film distance was set to 1.5 meters. Sagittal spinal canal diameter and anteroposterior diameter of the cervical vertebral body at the mid-vertebral bodies from C3 to C6 were measured. The canal body ratio (CBR) was given by dividing the diameter of the spinal canal by that of the vertebral body to assess the tightness of the spinal canal, and also to eliminate the magnification effect of radiographs.

Evaluation of measurement errors

Errors during measurements and data processing were assessed. First, to determine the difference between true and measured values, the diameter and area of a metal disc with known values were measured and compared. Inter- and intra-observer errors were evaluated as follows. The MR images of two males and two females were randomly selected from each age group (24 subjects in total), and two spine surgeons (M Ishikawa and M Matsumoto) measured the spinal cord area at the C4–5 level and C5 level three times each to evaluate inter-observer errors. The measurements were repeated one month later to evaluate intra-observer errors.

Statistical analyses

Statistical analyses were performed using a 'Statview 4.5' (Abacus Concepts, Int., Berkeley). Correlation between the spinal cord area and RAPT with age, height and body weight of the subjects were evaluated using Pearson correlation coefficient. ANOVA was used to evaluate the differences in the transverse area and RAPT among different age groups, while the paired *t*-test was used to evaluate inter- and intra-observer errors. *P* values less than 0.05 were considered significant.

Results

Evaluation of measurement errors

The mean area of the metal disc measured by the software was 337.99 ± 1.67 mm², which was 97.6% of the real size. The coefficient variable was 0.49%. Regarding inter- and intra-observer errors, there was no significant difference in measured values between the two observers ($P=0.094$ at C4–5, $P=0.081$ at C5) or between the two measurements performed at separate times by a single observer ($P=0.318$ at C4–5, $P=0.227$ at C5).

Spinal cord area

The mean transverse area of the spinal cord was largest at the C4 vertebral level in both males and females, for each age group. Generally, the transverse area was largest in subjects in their twenties and it decreased

with age. Males had significantly larger spinal cord areas than females in all age groups except teenagers. The mean transverse areas at C4 in males and females were $91.8 \pm 9.7 \text{ mm}^2$ and $95.2 \pm 8.0 \text{ mm}^2$ in teenagers, $100.7 \pm 9.7 \text{ mm}^2$ and $98.7 \pm 9.6 \text{ mm}^2$ in those in their twenties, $99.0 \pm 7.8 \text{ mm}^2$ and $91.1 \pm 10.0 \text{ mm}^2$ in those in their forties, and $86.4 \pm 9.1 \text{ mm}^2$ and $85.1 \pm 8.3 \text{ mm}^2$ in those older than 60 years of age respectively (Figures 2 and 3). The correlation coefficients between spinal cord area and age after twenties, at each level, ranged from -0.23 at C3–4 to -0.47 at C5–6 in males and from -0.31 at C6 to -0.47 at C3 in females. The spinal cord area correlated negatively with age in both males and females ($P < 0.05$).

The correlation coefficients between spinal cord area and height at each level were between 0.28 and 0.55 in males and between 0.24 and 0.27 in females, and the spinal cord areas were correlated positively with height both in males and females ($P < 0.05$). The correlation coefficients between spinal cord area and body weight at each level were between 0.03 and 0.19 in males and between 0.01 and 0.09 in females (statistically not significant).

RAPT

The mean RAPT was smallest at the C5–6 intervertebral level and largest at the C3 vertebral level in males and

females of any age groups. The mean RAPT at the C5–6 intervertebral level in males and females were $55.6 \pm 4.6\%$ and $54.4 \pm 4.4\%$ in teenagers, $54.6 \pm 3.9\%$ and $55.2 \pm 3.9\%$ in those in their twenties, $55.5 \pm 3.7\%$ and $54.3 \pm 3.7\%$ in those in their forties and $53.5 \pm 3.4\%$ and $54.7 \pm 5.2\%$ in those older than 60 years of age respectively. There was no significant gender difference in RAPT. The correlation coefficients between RAPT and age, height, and body weight, at each level, ranged between -0.17 and 0.19 in males and between -0.16 and 0.10 in females (statistically not significant).

Canal Body Ratio (CBR)

The mean CBR in males and females were 0.82 ± 0.20 and 0.90 ± 0.12 at C3 vertebral level, 0.82 ± 0.20 and 0.91 ± 0.13 at C4 vertebral level, 0.86 ± 0.18 and 0.95 ± 0.15 at C5 vertebral level, 0.86 ± 0.18 and 0.95 ± 0.13 at C6 vertebral level respectively (Figure 4).

The correlation coefficients between CBR and age ranged from -0.57 to -0.64 in males, and from -0.23 to -0.42 at each level in females ($P < 0.05$). The CBR significantly decreased with age in both gender. The correlation coefficients between CBR and the transverse area of the spinal cord ranged from 0.02 to 0.12 in males, and from 0.25 to 0.39 in females at each level. The CBR had weak or no correlation with the transverse area of the spinal cord.

Figure 2 Spinal cord area in males. Spinal cord area at each vertebral (A) and intervertebral level (B) decreased with age after 20 years of age. ($P < 0.05$, ANOVA)

Figure 3 Spinal cord area in females. Spinal cord area at each vertebral (A) and intervertebral level (B) decreased with age after 20 years of age. ($P < 0.05$, ANOVA)

Figure 4 CBR at each level

Discussion

There have been several studies on the transverse area and RAPT of the spinal cord measured on MR images.^{6–10} Sherman *et al.* found no correlation between spinal cord area and age, gender or body weight.⁶ Tanaka and Tanida reported spinal cord area to have no correlation with age.^{10,11} Suzuki *et al.*⁹ reported spinal cord area to correlate negatively with age but positively with height. The results of these studies are not consistent, partly because the number of subjects was small and the age distribution was not uniform. In the present study, the number of the subjects was sufficiently large for statistical analyses and the age and gender distribution of the subjects were almost equal among each age group. Moreover, the measurement methods were validated by the evaluation of possible errors.

As a result, we found that transverse spinal cord area correlated negatively with age and positively with height but not with body weight. RAPT did not correlate with age. This means that the cervical spinal cord decreases in size with aging while maintaining its shape. The decrease in transverse area of the spinal cord with aging may be attributable to age-related atrophy of the spinal cord or to the differences in body size between young and aged populations, although further study is needed to clarify these issues.

The spinal cord area at each level was smaller in teenagers than the twenties, although the difference was not statistically significant. It is believed that the spinal cord reaches maturity in early childhood, however, subtle growth of the spinal cord may occur in adolescence. This should be investigated by further study that is focused on pediatric population.

Sherman *et al.* showed that in his study the average spinal cord area at C4 in normal subjects was 121.8 mm².⁶ In the present study, the average spinal cord area at C4 in normal subjects was 94.6 mm². The large difference in the spinal cord area between the two studies may be related not only to pulse sequence in MRI, but also to racial difference in the height of the subjects, since height is positively correlated with the spinal cord area, as shown in this study.

Although MRI has enabled us to evaluate the cervical spinal cord area non-invasively, we must be cautious in interpreting the data obtained, since the values of the spinal cord area may depend on the pulse sequences utilized. Miyasaka performed a basic study in which spinal cord area was measured.¹² He found measured spinal cord area to be larger on T1 weighted images and smaller on T2 weighted axial images than the actual size of the spinal cord and attributed this to the data truncation effect which arises at the boundary of the spinal cord and cerebrospinal fluid during the Fourier transformation process.^{13–15} He also found that, on T1 weighted images, the spinal cord area was close to the real value if the window level was set to the average MR values of the spinal cord and cerebrospinal fluid. Suzuki *et al.*⁹ studied the reliability of MR measurement of the spinal cord. They scanned and measured a formalin-fixed cadaveric spinal cord and found that measurements made on T1-weighted MR images yielded nearly the same values as the actual spinal cord. Based on these previous studies, we used T1 weighted images to make our measurements.

Wolf stated the decreased sagittal spinal canal diameter would be one cause of the compressive myelopathy,¹⁶ and measuring the sagittal spinal canal diameter is widely accepted for one diagnosing method of the compressive myelopathy.^{17,18} CBR, which eliminates the magnification effect or radiographs, is a good alternative to measurement of the sagittal spinal canal diameter.¹⁹ In this study, CBR significantly decreased with age, and this may suggest the bony cervical spinal canal would be narrower with aging even in asymptomatic subjects. The results of this study showed that the correlation between spinal cord area and CBR and between RAPT and CBR were not statistically significant. These findings indicate that the spinal cord area and the shapes of the spinal cord are independent of the spinal canal diameter in asymptomatic subjects of any age groups. This may suggest that an individual with a narrow spinal canal does not always have a small or flat spinal cord. Therefore, patients with negative balance of the spinal cord and the spinal canal do exist, and they may possibly be subject to spinal cord compression.

In summary, the transverse area of the cervical spinal cord area measured on MRI decreased with age, while RAPT remained unchanged. The bony spinal canal would be narrower with age. But there was no significant correlation between the transverse area and the bony spinal canal diameter. These facts should be considered in evaluation of radiological findings of patients with cervical spinal disorders.

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