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What Is the Most Representative Parameter for Describing the Size of the Atlas? CT Morphometric Analysis of the Atlas with Special Reference to Atlas Hypoplasia

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Abstract

The spinal canal diameter (SCD) is one of the most studied factors for the assessment of cervical spinal canal stenosis. The inner anteroposterior diameter (IAP), the SCD, and the cross-sectional area (CSA) of the atlas have been used for the evaluation of the size of the atlas in patients with atlas hypoplasia, a rare form of developmental spinal canal stenosis, however, there is little information on their relationship. The aim of this study was to identify the most useful parameter for depicting the size of the atlas. The CSA, the IAP, and the SCD were measured on computed tomography (CT) images at the C1 level of 213 patients and compared in this retrospective study. These three parameters increased with increasing patient height and weight. There was a strong correlation between IAP and SCD (r = 0.853) or CSA (r = 0.822), while correlation between SCD and CSA (r = 0.695) was weaker than between IAP and CSA. Partial correlation analysis showed that IAP was positively correlated with SCD (r = 0.687) and CSA (r = 0.612) when CSA or SCD were controlled. SCD was negatively correlated with CSA when IAP was controlled (r = –0.21). The IAP can serve as the CSA for the evaluation of the size of the atlas ring, while the SCD does not correlate with the CSA. As the patient height and weight affect the size of the atlas, analysis of the spinal canal at the C1 level should take into account physiologic patient data.

Key words: atlas, atlas hypoplasia, inner anteroposterior diameter, measurement

Introduction

Narrowness of the cervical spinal canal has been regarded as an important risk factor for the development of cervical spondylotic myelopathy.[1–4] Degenerative changes or instability can reduce the diameter of the spinal canal and lead to spinal-cord compression. In addition, a congenital factor that affects the pathology is known as "developmental spinal canal stenosis".[5,6] As the spinal canal involves lamina and vertebral bodies at the subaxial level, the anterior-posterior spinal canal diameter (SCD) is frequently used for the evaluation of developmental spinal canal stenosis (Fig. 1).

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Although rare, atlas hypoplasia is reported to elicit spinal canal stenosis at the C1 level;[7–22] this has been reported as "developmental spinal canal stenosis" at the C1 level. Anatomically, the atlas ring and the odontoid process and ligaments constitute the SCD at the C1 level. While concomitant factors affect the length of the SCD, the size of the atlas remains the same (Fig. 2). Therefore, if atlas hypoplasia is defined as smallness of the ring due to congenital factors, it is doubtful that the SCD is a representative parameter of atlas hypoplasia as is the case in subaxial spinal canal stenosis.

Because earlier radiological studies applied the inner anterior-posterior diameter (IAP), the spinal canal diameter, and the cross-sectional area (CSA) of the atlas independently to evaluate atlas hypoplasia,[7–24] the parameter most useful for determining the size of the atlas remains to be elucidated. The aim of the present study was to evaluate these atlas

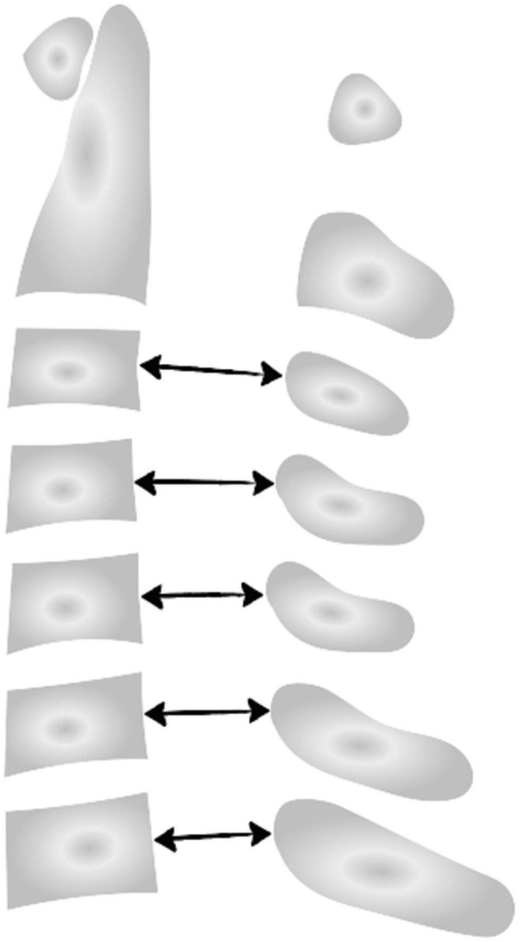

Fig. 1 Measurement of the spinal canal diameter at the cervical spinal column.

parameters and to identify the one most useful for determining the size of the atlas.

Methods

The ethics committee of Kagoshima University approved this retrospective study. Of 213 patients seen at Kagoshima University Hospital for a check-up of the head or cervical region before cranial surgery, or for post-operative follow-up, 173 had brain tumors, 9 had aneurysms, 13 presented with other cereberovascular diseases, 12 suffered hemifacial spasm or trigeminal neuralgia, 3 had epilepsy, and 3 were Parkinson patients. We excluded patients with symptomatic spinal canal stenosis at any level of the cervical spine, atlantoaxial instability, anomalies such as atlas assimilation or basilar invagination, and abnormal findings at the posterior arch of the atlas.

Head or cervical computed tomography (CT) findings with three-dimensional (3D) reconstruction were used in this study. Axial and sagittal CT images were acquired using 5-mm-thick slices. We selected the largest spinal canal on sagittal CT images and measured the IAP and the SCD of C1 (Fig. 3A). We also used axial CT images passing the mid-portion of the atlas and recorded the CSA (Fig. 3B). The IAP was measured from the posterior-most portion of the anterior arch of the atlas to the anterior-most portion of the posterior arch of the atlas (Fig. 3C). The SCD was measured from the posterior edge of the odontoid process to the anterior most portion of the posterior arch of the atlas (Fig. 3C). The SCD was measured along the same line for the measuring of the IAP. The CSA was traced along the inner cortical surface of the atlas using a manual cursor and recorded automatically on the PACS system (Synapse PACS 4.1.3, Fuji Film Medical Systems) (Fig. 3C).[23]

All measurements were carried out by 2 independent observers on 2 separate occasions. Intra- and interobserver agreement was evaluated as the intraclass coefficient of correlation (ICC) where < 0.40 = poor-, 0.40–0.75 = fair to good-, and > 0.75 = excellent agreement.[25]

IAP, SCD, and CSA measurements obtained in patients grouped by gender were compared

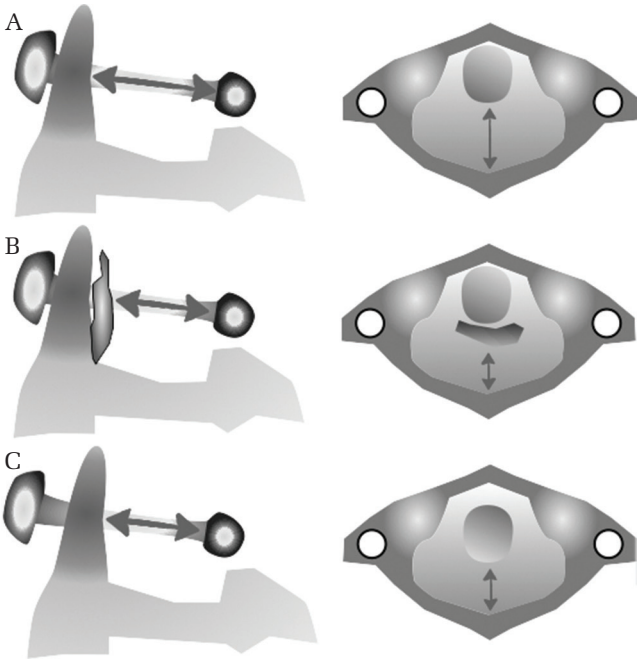

Fig. 2 Measurement of the spinal canal diameter at the C1 level in the absence of abnormality (A) and in the presence of ossification of the ligaments (B) or atlantoaxial instability (C). Note the cross sectional area of the atlas is the same from A to C, however, the spinal canal diameter is different due to concomitant pathology.

using the unpaired Student *t*-test. The correlation between these parameters was analyzed with the Pearson correlation coefficient (*r*). Partial correlations were performed to evaluate the relationship between IAP, SCD and CSA. Statistical analyses were performed using SPSS ver. 24.0 (SPSS Inc, Chicago, IL, USA). Differences of $P < 0.05$ were considered statistically significant.

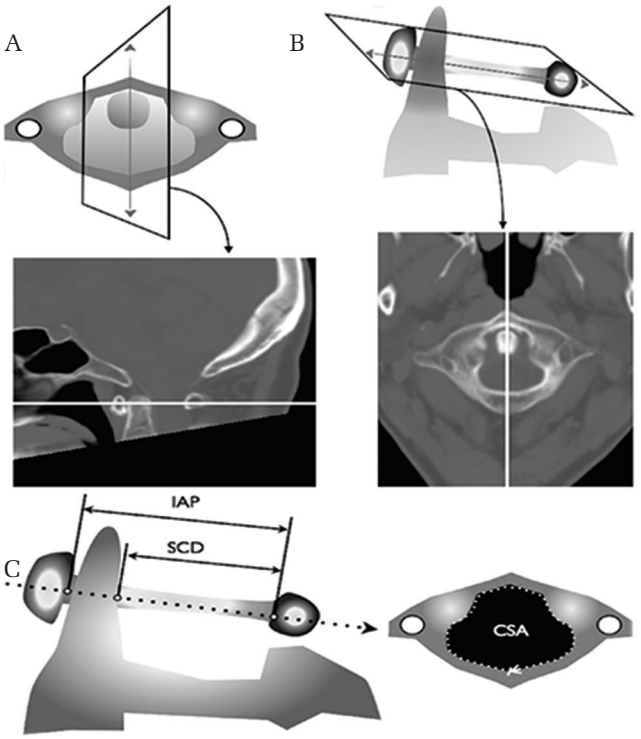

Fig. 3 Sagittal reconstruction CT scan through the midline of the atlas shows the largest spinal canal size for the measurements of the inner anteroposterior diameter (IAP) and the spinal canal diameter (SCD). The *white line* indicates the slice level of the axial image in B. (A) Axial CT scan selected at the mid-portion of the atlas for the measurement of the cross-sectional area (CSA) of the atlas. The *white line* indicates the slice level of the sagittal image in A. (B) Illustration of the measurement method used in this study. The IAP was measured from the posterior-most portion of the anterior arch of the atlas to the anterior-most portion of the posterior arch of the atlas. The SCD was measured from the posterior edge of the odontoid process to the anterior-most portion of the posterior arch of the atlas. Measurements of the SCD were carried out along the same line as for measuring the IAP. The CSA was traced along the inner cortical surface of the atlas with a manual cursor (*white dotted line*).

Results

The final study population included 213 patients, 96 men and 117 women. Their age at the time of examination ranged from 20 to 88 years. A summary of their characteristics and radiological measurements is shown in Table 1. While the average age was not statistically different between men and women ($P = 0.92$, unpaired Student's *t*-test), the height and weight of males was statistically greater than of females ($P < 0.001$, unpaired Student's *t*-test).

We confirmed the accuracy of our radiographic measurements by calculating intra- and interobserver agreements. The intraobserver ICC value exceeded 0.91; the interobserver ICC values were 0.95 for IAP, 0.88 for SCD, and 0.90 for CSA, indicating excellent reproducibility of the measurements.

The average CSA was 603.7 ± 74 mm^2 for the total study population; it was 639 ± 75 mm^2 for males and 574 ± 60 mm^2 for females. The average IAP was 29.7 ± 2.0 mm for all patients; it was 30.7 ± 2.0 mm for males and 28.9 ± 1.6 mm for females; these values were 18.0 ± 1.8, 18.6 ± 1.9, and 17.6 ± 1.6 for SCD, respectively. The difference in the measurement values between men and women was statistically significant ($P < 0.001$, unpaired Student's *t*-test).

We examined the correlation between these parameters and the patients' physiological data. The height and weight exhibited a moderate correlation with CSA (height: $r = 0.539$, $P < 0.0001$, weight: $r = 0.413$, $P < 0.0001$) and IAP (height: $r = 0.512$, $P < 0.0001$, weight: $r = 0.449$, $P < 0.0001$) and a weak correlation with SCD (height: $r = 0.275$, $P < 0.0001$, weight: $r = 0.282$, $P < 0.0001$) (Table 2). There was a very weak negative correlation between the patient age and IAP ($r = -0.165$, $P = 0.02$) and SCD ($r = -0.110$, $p = 0.108$), and a weak negative correlation with CSA ($r = -0.204$, $P = 0.003$) (Table 2).

Table 1 Summary of measurements obtained in 213 patients

	Total	Men	Women
Numbers	213	96	117
Age (years)	59.4 ± 14	59.5 ± 15	59.3 ± 14
Height (cm)	158 ± 9.3	166 ± 7.3	153 ± 6.3
Weight (kg)	57.5 ± 12	64.6 ± 11	51.6 ± 9.1
IAP (mm)	29.7 ± 2.0	30.7 ± 2.0	28.9 ± 1.6
SCD (mm)	18 ± 1.8	18.6 ± 1.9	17.6 ± 1.6
CSA (mm^2)	603.7 ± 74	639 ± 75	574 ± 60

CSA: cross-sectional area of the atlas, IAP: inner anteroposterior diameter, SCD: spinal canal diameter.

Next, we examined the correlation of these three parameters. There was a very strong correlation between IAP and CSA ($r = 0.822$, $P < 0.0001$) and between IAP and SCD ($r = 0.853$, $P < 0.0001$). SCD showed a strong correlation with CSA ($r = 0.695$, $P < 0.0001$), however, it was weaker than the other correlations (Table 3).

Partial correlation analysis to determine the relationship of CSA, IAP, and SCD (Table 4) identified a correlation between IAP and CSA ($r = 0.612$, $P < 0.0001$) and between IAP and SCD ($r = 0.687$, $P < 0.0001$) when CSA and SCD, respectively, were controlled. The correlation between SCD and CSA was weakly negative when IAP was controlled; there was no statistically significant difference ($r = -0.21$, $P = 0.756$) (Table 4).

Discussion

We examined the relationship among the 3 parameters of the atlas that have previously been used to define atlas hypoplasia. Pearson correlation analysis showed that there was a strong correlation between IAP and CSA and partial correlation analysis revealed a partial correlation between CSA and IAP and SCD. Consequently, IAP can serve as the CSA for the evaluation of the size of the atlas ring. On the other hand, SCD, the most widely-used parameter for the evaluation of the spinal canal, did not correlate well with CSA at the C1 level. Lastly, the patient height and weight had a significant effect on the CSA-, IAP-, and SCD values.

The normal range of anatomical atlas ring measurements has been reported.[26–28] However, as they were primarily taken to determine surgical screw placement, measurements relating to hypoplasia are scarce.[11,24] To describe hypoplasia of the atlas, the parameters were the anterior-posterior diameter, the SCD, and the CSA of the atlas.[7–24]

Matsunaga et al.[23] who compared the anteroposterior diameter (equivalent to our IAP) and the CSA in normal- and Down syndrome children reported that the average anteroposterior diameter of the atlas and of the spinal canal area along the cross-section of the atlas were significantly smaller in children with Down syndrome than their controls. They concluded that in the presence of hypoplasia, the area of the atlas ring is smaller than normal, indicating the importance of measuring the CSA of the atlas.

Others used the inner sagittal diameter of C1, equivalent to our IAP, as the benchmark for evaluating the size of the atlas. Musha and Mizutani[11] who used lateral roentgenograms for the identification of atlas hypoplasia in the Japanese population reported that the average sagittal inside diameter, equivalent to our IAP, was 34.4 mm in women and 37.1 mm in men. They defined hypoplasia as a value with 2 standard deviations (SD) below the standard. We used bone-window CT scans to measure the size of the spinal canal and found that the average IAP was 28.9 mm in women and 30.7 mm in men, and thus smaller than in their study (Table 1). Considering the possibility of differences attributable to the film-focus distance, measurements obtained on bone-window CT scans may be more accurate and simple.

Table 2 Correlation efficient between patient's physiological parameters and three parameters for C1 anatomy

		Height (cm)	Weight (kg)	Age (years)
IAP	Correlation	0.512	0.449	–0.165
(mm)	*P* value	0.0001	0.0001	0.02
SCD	Correlation	0.275	0.282	–0.110
(mm)	*P* value	0.0001	0.0001	0.108
CSA	Correlation	0.539	0.413	–0.204
(mm^2)	*P* value	0.0001	0.0001	0.003

CSA: cross-sectional area of the atlas, IAP: inner anteroposterior diameter, SCD: spinal canal diameter.

Table 3 Pearson correlation coefficient and *P* value of the parameters

		CSA	IAP	SCD
CSA	Correlation	1	0.822	0.695
	P value		0.000	0.000
IAP	Correlation		1	0.853
	P value			0.000
SCD	Correlation			1
	P value			

CSA: cross-sectional area of the atlas, IAP: inner anteroposterior diameter, SCD: spinal canal diameter.

Table 4 Partial correlation analysis of the relationship of CSA, IAP, and SCD

		CSA	IAP	SCD
CSA	Correlation	1	0.612	–0.21
	P value		0.000	0.756
IAP	Correlation		1	0.687
	P value			0.000
SCD	Correlation			1
	P value			

CSA: cross-sectional area of the atlas, IAP: inner anteroposterior diameter, SCD: spinal canal diameter.

Kelly et al.[24] who used cervical spine specimens from Caucasian and African-American populations also measured the inner sagittal diameter of C1; they recorded as atlas hypoplasia findings with the lowest 2.5% of measurements. Their measurements in both men and women were 30.8 mm and close to our findings, even after taking into consideration ethnic differences (Table 1). Their findings suggest the IAP as the optimal parameter for defining atlas hypoplasia.[11,24] As IAP is strongly correlated with CSA (Tables 3 and 4) and IAP is easier to measure than CSA, we suggest that determining the IAP is appropriate for the assessment of atlas hypoplasia.

The antero-posterior diameter of the spinal canal is one of the most measured parameters for the assessment of the pathology of developmental spinal canal stenosis.[29] Case reports documented the association of cervical myelopathy with atlas hypoplasia[7–22] and attributed atlas hypoplasia to narrowness of the SCD at the level of the atlas.[7–10,12–17,19–22] We found a positive correlation between SCD and IAP and CSA by using Pearson correlation analysis. As none of our patients manifested any sign of spinal canal stenosis (Fig. 2A), the strong correlation between SCD and IAP or CSA appears reasonable. However, when the effect of IAP was controlled in partial correlation analysis, SCD did not correlate with CSA, indicating that the correlation was spurious. As the size of the SCD may not reflect smallness of the atlas ring, we think that the SCD is not suitable for the definition of atlas hypoplasia.

The patient height and weight were moderately correlated with IAP and CSA (Table 2), indicating that the size of the atlas ring increases with increasing height or weight. As SCD was affected by other factors including the odontoid process, ligaments, and instability, the weak correlation between SCD and these physical parameters appears reasonable. The patient age had a weak negative effect on these parameters. Comparative studies to assess spinal canal stenosis generally include age- or gender-matched controls. Based on our findings, we suggest that investigations on atlas hypoplasia take the height and/or weight of subjects into account when control groups are designed.

In the present study, the IAP strongly correlated with the SCD ($r = 0.853$, $P < 0.0001$), suggesting that the smallness of the atlas ring can result in narrowing of the spinal canal at the C1 level. The spinal canal diameter was generally largest at C1 and became narrower downwards from C2 to C4 or C5.[30] These results suggest that developmental spinal canal stenosis can be present in the subaxial spine when the atlas is hypoplastic. We could not examine the subaxial spinal canal diameter in the present study because most of the measurements were carried out on head CT images. Kelly et al.[24] examined the spinal canal diameter at the C3 level and compared their measurements with the size of the atlas. They found that there was only a moderate correlation between the spinal canal diameter at C1 and at C3 ($r = 0.497$, $P < 0.001$). Further studies are required to determine whether the size of the atlas can be associated with the spinal canal diameter at the subaxial level.

Our study has some limitations. First, it did not include a truly normal population. It is possible that diseases in our subjects affected the measured values of the atlas. Second, all patients were Japanese and older than 20 years; it is not clear whether our findings can be extrapolated to non-Japanese individuals. Third, we focused on the inner portion of the atlas and did not measure outer anatomical features such as the size of the anterior arch, the posterior arch, and the lateral mass of the atlas. As these parameters have been determined for surgical screw placement[26–28], we did not address them. Based on our findings, we suggest that the size of the atlas ring be determined by using several inner as well as outer parameters.

Conclusion

We examined the relationship among three parameters that have been used for the definition of atlas hypoplasia in earlier studies. While the IAP can serve as the CSA for the evaluation of the smallness of the atlas ring, the SCD does not correlate with the CSA. The size of the atlas was significantly affected by the subject's height and weight, therefore, analysis of the spinal canal at the C1 level should take physiological data into account.

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Conflicts of Interest Disclosure

The authors did not receive funding for this work. All authors who are members of the Japan Neurosurgical Society (JNS) have registered online Self-reported COI Disclosure Statement Forms through the website for JNS members.

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