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ORIGINAL ARTICLE

A three-dimensional study of the atlantodental interval in a normal Chinese population using reformatted computed tomography

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Abstract The atlantodental interval has been usually used for the evaluation of atlantoaxial instability. However, the asymmetry of the lateral atlantodental interval is occasionally found in healthy individuals. Controversy therefore exists as to the clinical significance of this asymmetry in patients after trauma. The purpose of this study was to determine the normal range of atlantodental intervals in normal individuals using reformatted computed tomography. In this study, C1–C2 vertebrae were imaged in 230 adult patients by a Lightspeed Vct CT (General Electric, CT, USA) with a slice thickness of 0.625 mm. After reformatting the original images, the anterior atlantodental interval (AADI) and lateral atlantodental interval (LADI) were measured. The AADI was found to be 1.83 ± 0.46 mm (0.9–3.4 mm) in males and 1.63 ± 0.43 mm (0.5–3.2 mm) in females. The AADI was significantly greater in males than in females ($p < 0.05$). The 95% confidence interval for AADI was 1.75–1.90 mm in males and 1.54–1.72 mm in females. No statistically significant differences were found between males and females in the left and right LADI, and LADI asymmetry. The left LADI was found to be 3.38 ± 0.87 mm (1.7–6.0 mm), and the right LADI was 3.42 ± 0.84 mm (1.7–5.9 mm) in males, while the left LADI was 3.30 ± 0.73 mm (1.5–5.3 mm) and the right LADI was 3.37 ± 0.92 mm (1.7–5.9 mm) in females. The 95% confidence interval for left LADI was 3.23–3.52 and 2.94–3.25 mm, and for right LADI was 3.27–3.56 and 3.18–3.56 mm in males and females, respectively. The mean asymmetry of LADI was 0.76 ± 0.66 mm (0.0–3.5 mm) in males and 0.73 ± 0.70 mm (0.0–3.7 mm) in females. The 95% confidence interval for LADI asymmetry was 0.65–0.87 mm in males and 0.59–0.88 mm in females. Most of the population was found to have an asymmetry ranging between 0.1 and 2.0 mm. The current study shows that LADI asymmetry is common in patients without any cervical spine abnormalities. LADI asymmetry may be a normal anatomic variant and there is no evidence to confirm that LADI asymmetry is a sensitive or specific indicator of traumatic atlantoaxial instability. Radiologists and clinicians should be aware of this normal range of asymmetry when interpreting CT scans of the atlantoaxial region.

Keywords Atlantoaxial interval · Asymmetry · Cervical spine · Reformatted computed tomography · Chinese

Introduction

Conventional radiographs have been widely used to evaluate individuals with suspected cervical spine injuries. However, owing to the complicated nature of the atlantoaxial region with its many overlapping structures, it is inadequate to fully evaluate this region on conventional radiography or routine computed tomography (CT) [10, 14]. Spiral CT with multiplanar reconstructions can distinctly display the atlantoaxial joints and help to increase

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the diagnostic accuracy of atlantoaxial disorder [4, 5, 7, 16, 20]. With widespread use and high sensitivity, thin-section axial CT has become the standard choice of initial assessment of cervical spine trauma [3, 16, 20].

The atlantodental interval, including the lateral atlantodental interval (LADI) and anterior atlantodental interval (AADI), has been widely used for the evaluation for atlantoaxial instability [9, 15, 17]. However, the sensitivity and specificity of the atlantodental interval, especially the LADI, in evaluating the instability of the atlantoaxial region is still controversial because LADI asymmetry is occasionally found in patients with a few or no symptoms following trauma, and in healthy patients as well. Some authors [13, 15, 21] believe that this asymmetry may be a normal variant and is unreliable for detecting atlantoaxial instability, while others [1, 9, 22] consider that LADI asymmetry in patients, following trauma, may represent atlantoaxial rotatory subluxation or fixation.

The atlantodental interval has been studied extensively using conventional radiographs and ordinary CT scans in symptomatic and asymptomatic trauma patients [11, 13, 15, 17, 21]. Mirvis [16] indicated that the C1–C2 lateral articular relationships could be best shown using a thin-section axial CT with multiplanar reconstructions. We are unaware of any previous studies of the atlantodental interval performed in a large group of Chinese patients, without any cervical spine abnormalities, using reformatted CT to date. This study should help radiologists and clinicians in evaluating upper cervical injuries in a Chinese population.

The purpose of this study was to determine the normal value range of the atlantodental interval in a large group of normal individuals.

Materials and methods

In this study, 500 patients who had sinus, throat, or neck CT scans for reasons unrelated to cervical spine dysfunction were sampled from the patients' registry between September 2009 and September 2010. Those who had a history of cervical spine abnormalities (cervical spine trauma, congenital deformity, infection, rheumatoid arthritis, or primary and secondary tumors) were excluded from this study. The population finally consisted of 140 males (age range 20–50 years), and 90 females (age range 20–50 years). There was no significant difference in the age of males and females. This study was conducted retrospectively.

All of the scans were performed in a neutral head position. The C1–C2 vertebrae were scanned continuously with a slice thickness of 0.625 mm using a Lightspeed Vct CT (General Electric) scanner in all patients.

Multiplanar reconstruction was constructed parallel to the *X*-axis with 0.625 mm thick slices in the VR (volume rendering) images (Fig. 1a) to obtain the transverse section of the atlantoaxial joint (Fig. 1b). From these transverse images, reformatted CT slices were performed with sagittal (parallel to the *Y*-axis) and coronal reconstructions (parallel to the *X*-axis) to get sagittal and coronal planes, respectively. Finally, the mid-sagittal and mid-coronal image of the dens were chosen for measuring parameters as follows and is shown in Fig. 1c, d:

1. AADI, anterior atlantodental interval;
2. LADI, lateral atlantodental interval;
3. LADI asymmetry: the absolute value of variance of left LADI and right LADI.

Statistical analysis

To ensure consistency of data, all parameters were measured twice by two independent observers. No variability was observed in the results of the intra-observer and inter-observer (Table 1). Therefore, the measurements of two independent observers were combined and averaged. Mean values, standard deviations, and 95% confidence intervals of AADI, LADI, and the LADI asymmetry were calculated for male and female groups. Statistical analyses were performed using SPSS software. A p value <0.05 was considered statistically significant.

Results

The results are summarized in Tables 2, 3, 4, and 5.

Anterior atlantodental interval (AADI)

The AADI was found to be 1.83 ± 0.46 mm in males and 1.63 ± 0.43 mm in females (Table 2). The AADI was significantly greater in males than in females ($p < 0.05$). The upper limit of normal was 3.4 mm in males and 3.2 mm in females. The 95% confidence interval for AADI was 1.75–1.90 mm in males, and 1.54–1.72 mm in females (Table 3). Most of our subjects have an AADI ranging between 1.0 and 3.0 mm (Table 4).

Lateral atlantodental interval (LADI)

The left LADI was found to be 3.38 ± 0.87 mm, and the right LADI was 3.42 ± 0.84 mm in males, while the left LADI was 3.30 ± 0.73 mm and the right LADI was 3.37 ± 0.92 mm in females. The upper limit of normal LADI was 6.0 mm on the left and 5.9 mm on the right in males, and was 5.3 mm on the left and 5.9 mm on the right

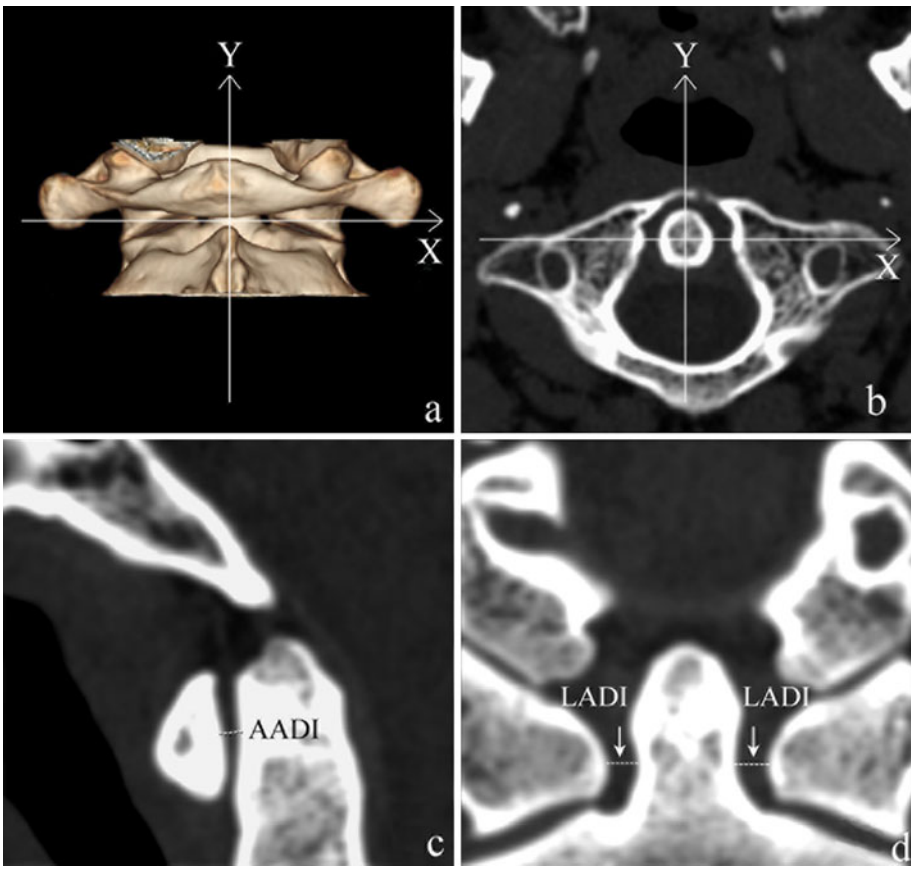

Fig. 1 Multiplanar reconstruction was constructed parallel to the *X*-axis with 0.625 mm thick slices in the VR (volume rendering) images (**a**) to obtain the transverse section of the atlantoaxial joint (**b**). Then from these transverse images, reformatted CT slices were performed with sagittal (parallel to the *Y*-axis) and coronal reconstructions (parallel to the *X*-axis) to get sagittal and coronal planes, respectively. Finally, the mid-sagittal and mid-coronal image of the dens were chosen for measuring parameters as illustrated (**c**, **d**)

Table 1 The results of intra- and inter-observer variation in AADI and LADI

	AADI (*r*)	Left LADI (*r*)	Right LADI (*r*)
Intraclass correlation	0.9773†	0.9927†	0.9939†
Interclass correlation	0.9669†	0.9872†	0.9943†

AADI anterior atlantodental interval, *LADI* lateral atlantodental interval, *r* correlation coefficient

† Statistically significant difference, $p < 0.001$

Table 2 Tabulated results (mean ± SD) of AADI, LADI and LADI asymmetry

Group	AADI (mm)	LADI (mm)		LADI asymmetry (mm)
		Left	Right	
Male	1.83 ± 0.46	3.38 ± 0.87	3.42 ± 0.84	0.76 ± 0.66
Female	1.63 ± 0.43*	3.30 ± 0.73	3.37 ± 0.92	0.73 ± 0.70

AADI anterior atlantodental interval, *LADI* lateral atlantodental interval

Comparison between males and females: * statistically significant difference, $p < 0.05$

in females (Table 2). The 95% confidence interval for left LADI was 3.23–3.52 and 2.94–3.25 mm, and for right LADI was 3.27–3.56 and 3.18–3.56 mm in males and females, respectively (Table 3). No statistically significant differences were found between males and females in either the left or right LADI ($p > 0.05$).

Lateral atlantodental interval asymmetry

The mean asymmetry of LADI was 0.76 ± 0.66 mm in males and 0.73 ± 0.70 mm in females (Table 2). There was no statistically significant difference between males and females in the values of LADI asymmetry ($p > 0.05$). The maximum LADI asymmetry was 3.5 mm in males and 3.7 mm in females. The 95% confidence interval for LADI asymmetry was 0.65–0.87 mm in males and 0.59–0.88 mm in females (Table 3). The majority of our population was found to have an asymmetry ranging between 0.1 and 2.0 mm. Only 5.83% of the population (14 out of the 230 patients) was observed to have an asymmetry ≥2.0 mm in the current study (Table 5).

Discussion

The atlantodental interval of the atlantoaxial joint, including the LADI and the AADI, has been studied extensively using conventional radiographs and used widely in the evaluation for atlantoaxial instability [9, 17].

Table 3 Tabulated results of 95% confidence interval and the range for AADI, LADI and LADI asymmetry

Group	AADI (range)	LADI (range)		LADI asymmetry (range)
		Left	Right	
Male	1.75, 1.90 (0.9–3.4)	3.23, 3.52 (1.7–6.0)	3.27, 3.56 (1.7–5.9)	0.65, 0.87 (0.0–3.5)
Female	1.54, 1.72 (0.5–3.2)	2.94, 3.25 (1.5–5.3)	3.18, 3.56 (1.7–5.9)	0.59, 0.88 (0.0–3.7)

AADI anterior atlantodental interval, *LADI* lateral atlantodental interval

Table 4 Number of different AADI values

AADI	0–1 mm	1–2 mm	2–3 mm	≥3 mm
Male	1	93	43	3
Female	2	72	14	2

AADI anterior atlantodental interval

Table 5 Number of different LADI asymmetry values

LADI asymmetry	0 mm	0–1 mm	1–2 mm	≥2 mm
Male	10	87	34	9
Female	8	53	24	5

LADI lateral atlantodental interval

In the cervical spine trauma setting, an increased AADI or LADI asymmetry may indicate disruption of the ligaments of the atlantoaxial region and the dissociation of the atlantoaxial joint, such as for atlantoaxial rotatory subluxation or fixation [9, 20].

The anterior atlantodental interval (AADI), described by Hinck and Hopkins [12], is known as the predental space (Fig. 1d). Hinck indicated that the normal maximum AADI is held to be ≤3 mm in males and ≤2.5 mm in females. The AADI is maintained by the presence of the atlantodental ligament, alar ligaments, and transverse atlantal ligament. Previous studies indicated that an abnormally widened atlantodental interval may be an indirect indicator of subluxation or injury to the atlantoaxial junction ligament, but observing the abnormal contraposition of articular facets of lateral atlantoaxial joints can further provide the extent and types of subluxation [2, 4]. Our results show that the AADI was <3.0 mm in most males (97.9%) and <2.5 mm in most of the females (97.7%), consistent with the Hinck and Hopkins [12] study. Therefore, we also believe that an abnormally widened AADI in patients following acute cervical trauma may indicate injuries to the atlantoaxial region.

The status of the LADI is routinely evaluated for spreading of the lateral masses of C1 and for lateral atlantodental interval asymmetry [8, 9, 13, 15, 18]. Asymmetry of the LADI has been considered in the literature to represent a sign of atlantoaxial instability. Fielding and Hawkins [9] concluded that asymmetry of the LADI in patients with a history of recent trauma is indicative of rotatory subluxation of the atlas on the axis. Wortzman and Dewar [22] proposed that persistent LADI asymmetry, with this asymmetry not being correctable by rotation, should be used as the basic radiological criteria for the diagnosis of atlantoaxial rotatory fixation. Ajmal and O'Rourke [1] studied 13 neck injury patients, with an LADI asymmetry ≥2.0 mm, and opined that LADI asymmetry may be a sign of significant cervical trauma.

However, controversy exists as to the clinical significance of LADI asymmetry in the trauma patients with a few or no symptoms. Lee [15] and Ellis [8] indicated that LADI asymmetry may be a normal radiographic finding and not in itself abnormal in the otherwise uninjured cervical spine. Iannacone et al. [13] studied a select group of trauma patients using dynamic CT and indicated that the finding of LADI asymmetry in conscious patients without cervical spine fixed deformity appears to be incidental and requires no further evaluation or treatment. Sutherland et al. [21] reported that a measurable asymmetry can be present in the neutrally positioned, ligamentously intact atlantoaxial complex and is not necessarily indicative of instability. More recently, Harty et al. [11] performed a CT study on 29 patients following acute cervical trauma, who were found to have LADI asymmetry on conventional radiographs, and identified that 32% of the patients had congenital LADI asymmetry in his study.

Previous studies have confirmed that the rotation of the head should lead to the asymmetry of the bilateral LADI [13, 16, 21]. Normally, as the head is turned in one direction, simultaneous rotation of the atlas on the axis and tilting of the atlas occurs. When the head is turned to the right, the left LADI is diminished and the right LADI is increased [16]. Dumas et al. [7] studied 10 normal subjects using three-dimensional CT and also indicated that with the head turned to the left, the right articular mass of the atlas moved anteriorly and medially, whereas the left lateral mass underwent posteromedial rotation. Recent studies have described an approximated instantaneous axis of rotation located at the level of the axis-odontoid process during C1–C2 axial rotation and have found that this axis

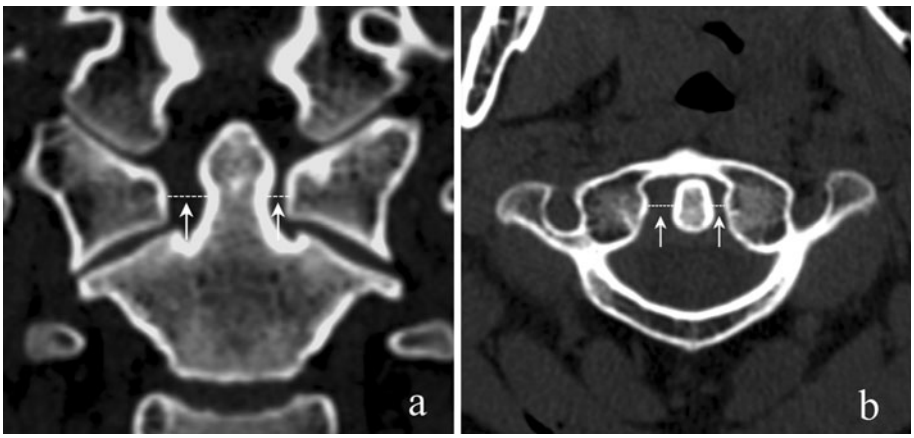

Fig. 2 A representative normal subject with LADI asymmetry on coronal (**a**) and transverse plane (**b**), respectively

should shift in direction of the lateral mass of the atlas opposite to the rotation direction [6, 19]. Therefore, all the CT scans were performed in a neutral head position in this study, aiming to diminish the influence of head rotation on the results.

In the current study, a high percentage of LADI asymmetry was observed in a large number of asymptomatic patients (Fig. 2). The majority of our population had an asymmetry ranging between 0.1 and 2.0 mm (males 93.6%, females 94.4%). The percentage of LADI asymmetry $\geq$1 mm was up to 30% in the present study compared with 46% in Rojas's [20] study. However, the majority of his subjects included patients who had sustained some form of trauma as an indication for the evaluation of the cervical spine. The patients who had a history of cervical spine abnormalities, including cervical spine trauma, were excluded from this study. Therefore, we believe that this study would establish a more accurate normal range of LADI asymmetry in a Chinese population.

In total, 14 patients were observed to have an LADI asymmetry $\geq$2.0 mm in the current study (9 males and 5 females). Even though sinus infections, tonsillitis and tonsillar abscesses might result in laxity of the transverse ligament, facet capsular ligaments, the tectorial membrane, and/or the alar ligaments, no diseases mentioned above were found in these patients with an LADI asymmetry. We also suggest that the finding of LADI asymmetry may be a normal anatomic variant in patients without any cervical spine abnormalities and trauma, and must be correlated with the clinical presentation to determine its clinical significance [16]. However, an abnormal LADI asymmetry in patients with an appropriate and acute injury mechanism, especially asymmetry superior to 2.0 mm, may be a sign of significant cervical instability and warrants a careful and further diagnostic evaluation [1, 21], such as dynamic CT scan or MRI, to confirm whether there is an abnormal alignment between C1 and C2.

In the current study, we mainly aim to identify the normal range of the atlantodental interval in patients without any cervical spine abnormalities. Comparison of LADI asymmetry between these patients and patients with true rotary atlantoaxial subluxation or fixation will be of significant clinical value. And it could be interested to study the correlation between the atlantodental interval and the age, height, weight and BMI of population. However, a statistically significant correlation could not be established because of the small sample size. Further studies will focus on studying the LADI asymmetry in patients with true rotary atlantoaxial subluxation or fixation, and the correlation between the atlantodental interval and the age, height, weight and BMI.

Conclusions

The current study shows that LADI asymmetry is common in patients without any cervical spine abnormalities. LADI asymmetry may be a normal anatomic variant and there is no evidence to confirm that LADI asymmetry is a sensitive or specific indicator of traumatic atlantoaxial instability. Radiologists and clinicians should be aware of this normal range of asymmetry when interpreting CT scans of the atlantoaxial region.

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