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Odontoid incidence: a constant cervical anatomical feature evident in standing plain radiographs and supine magnetic resonance images

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Abstract

Objective To assess whether there is a difference between measurements of odontoid incidence (OI) and other cervical sagittal parameters by X-ray radiography and those by supine magnetic resonance imaging (MRI).

Methods Standing X-ray and supine MRI images of 42 healthy subjects were retrospectively analyzed. Surgimap software was employed to measure cervical sagittal parameters including OI, odontoid tilt (OT), C2 slope (C2S), C0-2 angle, C2-7 angle, T1 slope (T1S) and T1S-cervical lordosis (CL). Paired samples t-test was applied to determine the difference between parameters measured by standing X-ray and those by supine MRI. In addition, the statistical correlation between the parameters were compared. The prediction of CL was performed and validated using the formula $CL = 0.36 \times OI - 0.67 \times OT - 0.69 \times T1S$.

Results Significant correlations and differences were found between cervical sagittal parameters determined by X-ray and those by MRI. OI was verified to be a constant anatomic parameter and the formula $CL = 0.36 \times OI - 0.67 \times OT - 0.69 \times T1S$ can be used to predict CL in cervical sagittal parameters.

Conclusions OI is verified as a constant anatomic parameter, demonstrating the necessity of a combined assessment of cervical sagittal balance by using standing X-ray and supine MRI. The formula $CL = 0.36 \times OI - 0.67 \times OT - 0.69 \times T1S$ can be applied to predict CL in cervical sagittal parameters.

Keywords Cervical sagittal parameters, Odontoid incidence, Odontoid tilt, C2 slope, CL prediction

Introduction

The incidence rate of cervical spondylosis increases steadily along with changes in lifestyle and population aging. Its main etiology is cervical disk herniation or foraminal stenosis, which causes radiating pain and

numbness in neck, shoulder, and upper extremity. They can lead to long-term disability, pain, and financial burden, and contribute to poor quality of life [1, 2].

Since the sagittal balance was reported to be significantly related to patients' health-related quality of life (HRQOL), the importance of sagittal alignment and sagittal balance has been gradually recognized [3]. Cervical sagittal imbalance is one of the main reasons for cervical disk degeneration and associated disorders [4–6]. Cervical sagittal balance-related parameters, including C0-2 angle (C0-2), C2–C7 cervical lordosis (CL), C2 slope (C2S), T1 slope (T1S), and T1S minus CL (T1S-CL)

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[7], are being used to evaluate the severity and treatment outcomes of the disease [8]. Odontoid incidence (OI) is one of the most important anatomic parameters in terms of cervical sagittal balance and equals the sum of the positional parameters odontoid tilt (OT) and C2S ($OI = OT + C2S$) [9]. OI strongly correlates with CL through C2S, thus largely determining the different cervical types and consequent mechanisms of cervical spine degeneration [9]. The analysis of OI is essential to understand the impact of cervical sagittal alignment and to make an surgical strategy for cervical deformity correction. OT indicates the spatial orientation of the odontoid process, which may vary depending on the balance of cranial and horizontal gaze, and could aid in two-dimensional analyzes of cervical alignment and balance [10].

Different imaging modalities such as standing X-ray radiography [10] and supine magnetic resonance imaging (MRI) [11] are commonly used to assess cervical spine alignment. However, body posture and the role of the head in cervical load-bearing may have an impact on the spine, leading to different results [12–14]. Standing X-ray provides gravity balance information; however, in patients with a short neck or high sternum, the endplates of the lower cervical and upper thoracic vertebrae may not be clear, thus affecting the measurement of cervical sagittal parameters [15]. Supine MRI can provide anatomical structure information of soft tissues with high spatial resolution [16]; however, it cannot reflect the natural upright state of the spine, since cervical balance is obtained in an upright posture. Therefore, to provide a more comprehensive and reliable reference for the prevention, diagnosis and treatment of cervical spine diseases, further studies investigating correlations and differences between cervical spine parameters measured by different imaging methods are needed. In this study, we assessed whether there was a difference between cervical sagittal parameters measured by standing X-ray and those by supine MRI and validated whether OI is a constant anatomic parameter. We explored correlations between cervical sagittal parameters and determined the formula for predicting cervical sagittal parameters.

Materials and methods

Case selection

Ethical approval was obtained from the Ethics Committee of our hospital. Adults aged between 18 and 40 aged without spinal symptoms were included in this study. All participants were selected from those population undergoing annual routine health checkups at the Center of Health Management, affiliated with The First Affiliated Hospital of Guangxi Medical University from January 1, 2011 to October 31, 2022.

Patient selection criteria

The following screening criteria were used for ensuring the health status of study participants and excluding factors that might interfere with results in order to improve the accuracy and reliability of the study.

All participants had to provide available clinical data, including standardized lateral cervical spine radiographs and MRI images to meet the inclusion criteria. Exclusion criteria included a history of cervical spine trauma, infection, tumor, deformity, history of cervical spine surgery, or history of other spinal trauma and disease to avoid measurement bias and disease progression. Additionally, individuals with diagnosed diseases, degenerative changes (e.g., decreased disk height or osteophyte formation), a history of treatment related to the cervical spine, a history of spinal surgery, or overall sagittal alignment abnormalities were excluded.

Acquisition conditions

The radiographic protocol was standardized. For each subject, cervical spine lateral radiographs were obtained with a 10×12-inch cassette at a 72-inch (182 cm) distance with the radiographic tube centered at the C4–C5 disk space with no magnification. Subjects were instructed to stand in a comfortable position and keep their eyes forward with their arms extended on their chests. The MRI images were obtained using a 1.5-T system (Signa; GE Medical Systems). Subjects were placed in the scanner chamber in a supine position. The cervical cord was imaged in neutral position with a standard MR receive coil (HD Head Neck and Spine Array) dedicated to spinal imaging. The T2-weighted MR images were acquired with a field of view (FOV) of 260 mm and a matrix size of 512×512 pixels. Later, MRI data was measured on T2-weighted MR images. The interval between X-ray and MRI examinations was not more than 2 months in each case to avoid the implications of disease progression for the results.

Data collection and measurement

Data was collected by one of investigators in the research team, who would not be involved in final data analysis. The assessment was performed by two senior spine surgeons (with 12 and 6 years' clinical experience, respectively). They performed the following measurements of cervical sagittal parameters on X-ray and MRI images using the Surgimap software (Nemaris, Inc., New York, NY, USA): OI, OT, C2S, C0-2 angle, C2-7 angle, T1S and T1S-CL. OI was defined as the angle between the line perpendicular to the C2 endplate (C2EP) at its midpoint and the line connecting this point to the center of the odontoid process. OT was defined as the angle created

by a line running from the C2EP midpoint to the center of the odontoid process and the vertical axis. C2S was defined as the angle between the C2EP and a horizontal line. The C0-2 angle, an angle between the C2EP and the McRae line was measured. The C2-7 angle was measured as the angle between C2 and C7 lower endplates. T1S was defined as an angle formed between the T1 upper endplate and the horizontal plane (Figs. 1, 2). Two assessors completed the measurements independently and averaged them for the final results.

Statistical analyzes

All data in this study was analyzed by using SPSS (version 26), R (version 4.2.2) and RStudio (version 1.1.463). Inter-observer agreement for each parameter was assessed by the intraclass correlation coefficient (ICC) [17], whose values are expressed as 95% confidence intervals (CI). The ICC takes values ranging from 0 to 1, with a larger value indicating a better agreement. According to the recommendations of Fleiss [18] and Landis [19], ICC values between 0.00 and 0.40 indicate poor agreement, between 0.40 and 0.74 indicate good agreement, and between 0.75 and 1.00 indicate excellent agreement.

In this study, all parameters are presented as mean \pm standard deviation. If the parameters

conformed to normal distributions, the paired t-test would be carried out to analyze the differences between X-ray and MRI. For correlation analysis between two imaging studies, the Pearson correlation test was used, which was expressed as r coefficient. The r coefficients ranging from -1.0 to -0.5 or 0.5 to 1.0 suggest strong correlation, -0.5 to -0.3 or 0.3 to 0.5 indicate moderate correlation, -0.3 to -0.1 or 0.1 to 0.3 represent weak correlation, and -0.1 to 0.1 imply no correlation or very weak correlation. A P value < 0.05 was considered to be statistically significant.

Results

A total of 96 individuals who participated in health checkups were screened in this study, from whom, 54 were excluded based on the exclusion criteria. The study population consisted of 42 participants [15 (35.7%) males and 27 (64.3%) females] with a mean age of 29.1 ± 5.97 (18–39 years old). The study involved the measurement of seven sagittal parameters and a total of 588 measurements were obtained. Two evaluators performed separately the measurements for the radiographic and MRI studies.

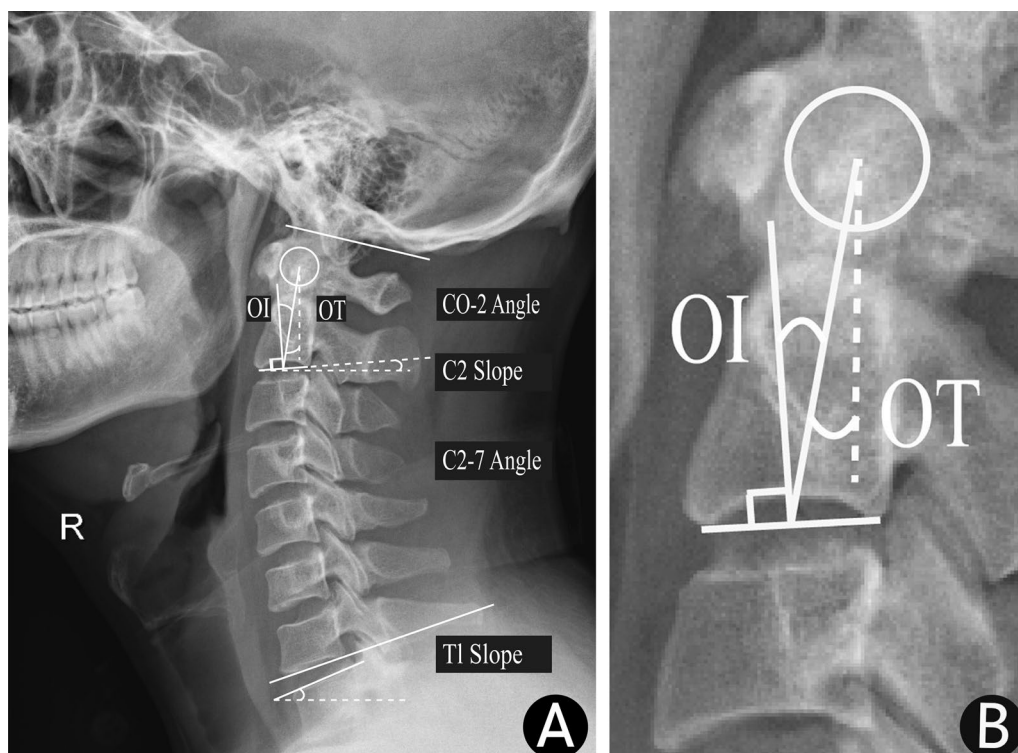


Fig. 1 Measurement of odontoid process parameters and cervical spine parameters on DR images. **A:** Measurement of OI, OT and cervical spine parameters on DR images of a healthy 35-year-old male; **B:** High-resolution views of OI and OT on DR images of a healthy 35-year-old male. DR, digital radiography; OI, odontoid incidence; OT, odontoid tilt

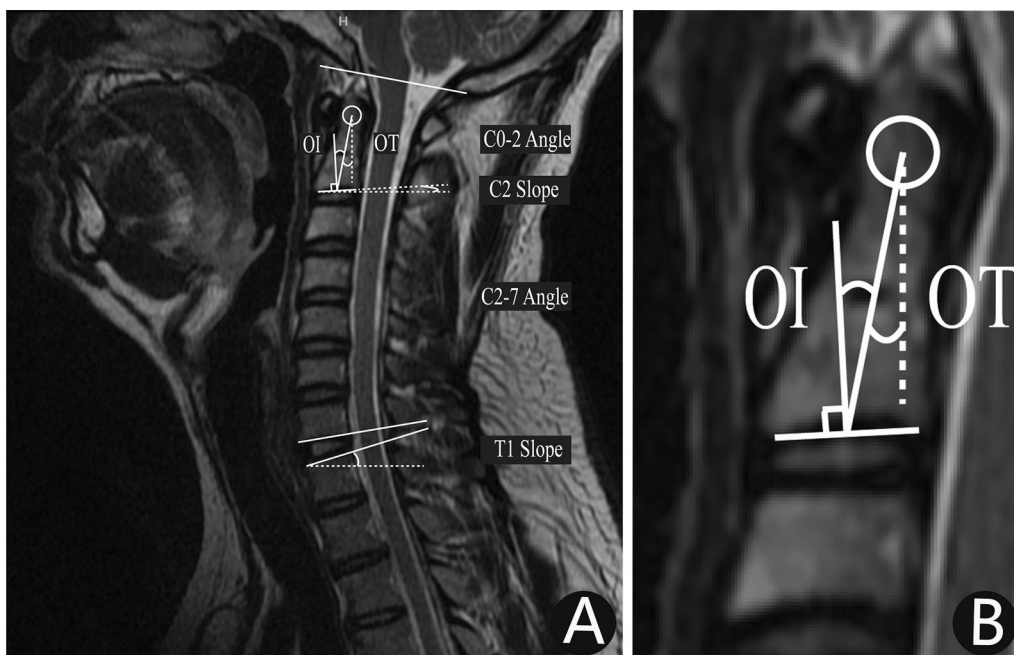


Fig. 2 Measurement of odontoid process parameters and cervical spine parameters on MRI images. **A:** Measurement of OI, OT and cervical spine parameters on MRI images of a healthy 35-year-old male; **B:** High-resolution views of OI and OT on MRI images of a healthy 35-year-old male. MRI, magnetic resonance imaging; OI, odontoid incidence; OT, odontoid tilt

Inter-observer agreement

By the credibility of analyzes, the inter-observer agreement of all cervical spine parameters on X-ray and MRI was as follows: X-ray: 0.552 (OI), 0.855 (OT), 0.907 (C2S), 0.942 (C0-2), 0.965 (C2-7), 0.952 (T1S), 0.897 (T1S-CL); MRI: 0.723 (OI), 0.819 (OT), 0.958 (C2S), 0.985 (C0-2), 0.963 (C2-7), 0.948 (T1S), 0.924 (T1S-CL). Except for the inter-observer agreement of 0.552 and 0.723 for OI on X-ray and MRI, respectively, both of which were in good agreement, the remaining parameters showed excellent agreement. This indicates that the overall inter-observer agreement was great and the results were statistically significant ($P < 0.001$) (Table 1).

Cervical sagittal parameters

The mean cervical sagittal parameters on X-ray were $15.38^\circ \pm 2.32^\circ$ (OI), $12.51^\circ \pm 6.18^\circ$ (OT), $2.8^\circ \pm 6.36^\circ$ (C2S), $24.6^\circ \pm 9.47^\circ$ (C0-2), $20.76^\circ \pm 9.73^\circ$ (C2-7), $31.71^\circ \pm 8.4^\circ$ (T1S), $10.95^\circ \pm 8.21^\circ$ (T1S-CL). The mean cervical sagittal parameters on MRI were $16.68^\circ \pm 4.33^\circ$ (OI), $5.44^\circ \pm 6.51^\circ$ (OT), $11.4^\circ \pm 6.83^\circ$ (C2S), $15.03^\circ \pm 6.26^\circ$ (C0-2), $12.24^\circ \pm 10^\circ$ (C2-7), $28.37^\circ \pm 7.21^\circ$ (T1S), $16.13^\circ \pm 8.17^\circ$ (T1S-CL). After X-ray and MRI paired t-test, the results were: $-1.29^\circ \pm 4.38^\circ$ (OI), $7.07^\circ \pm 7.39^\circ$ (OT), $-8.6^\circ \pm 7.03^\circ$ (C2S), $9.57^\circ \pm 9.68^\circ$ (C0-2), $8.52^\circ \pm 9.59^\circ$ (C2-7), $3.34^\circ \pm 7.42^\circ$ (T1S), $-5.19^\circ \pm 7.95^\circ$

Table 1 Inter-observer reliability and pairwise difference of each parameter between observers

Parameters	Observer		Inter-observer reliability	
	A ^a Mean (SD)	B ^a Mean (SD)	ICC	p
<i>DR</i>				
OI (°)	15.37 (2.35)	15.4 (3.18)	0.552	0.007
OT (°)	13.98 (6.27)	11.03 (6.68)	0.855	<0.001
C2S (°)	1.24 (6.27)	4.37 (6.68)	0.907	<0.001
C0-2 (°)	22.87 (9.72)	26.34 (9.47)	0.942	<0.001
C2-7 (°)	21.45 (9.94)	20.07 (9.81)	0.965	<0.001
T1S (°)	31 (8.13)	32.41 (9.00)	0.952	<0.001
T1S-CL (°)	9.55 (7.92)	12.35 (9.10)	0.897	<0.001
<i>MRI</i>				
OI (°)	15.9 (4.87)	17.45 (4.86)	0.723	<0.001
OT (°)	5.10 (7.01)	5.78 (7.14)	0.819	<0.001
C2S (°)	11.04 (7.02)	11.76 (6.90)	0.958	<0.001
C0-2 (°)	15.27 (6.28)	14.8 (6.32)	0.985	<0.001
C2-7 (°)	12.66 (10.28)	11.81 (10.07)	0.963	<0.001
T1S (°)	28.85 (7.13)	27.89 (7.62)	0.948	<0.001
T1S-CL (°)	16.19 (8.85)	16.08 (8.09)	0.924	<0.001

^a A, B represent the two observers who participated in the study

DR digital radiography; MRI magnetic resonance imaging; OI odontoid incidence; OT odontoid tilt; C2S C2 slope; T1S T1 slope; CL cervical lordosis

(T1S-CL). The results showed that there was no significant difference of OI in X-ray and MRI ($p > 0.05$), and OT, C0-2, C2-7, and T1S were significantly greater on X-ray than on MRI ($p < 0.05$), while C2S and T1S-CL were significantly smaller on X-ray than on MRI ($p < 0.05$) (Table 2).

X-ray and MRI parameter correlation

After Pearson’s analysis, the same cervical sagittal parameters on X-ray and MRI were found to be significantly correlated ($p < 0.05$), including C2-7 ($r = 0.528$), T1S ($r = 0.557$), T1S-CL ($r = 0.529$), C2S ($r = 0.433$), and OT ($r = 0.322$). Whereas, C0-2 and OI did not

have a significant correlation between X-ray and MRI ($p > 0.05$).

Parameter correlations

After Pearson’s analysis, the correlations between X-ray cervical spine parameters were as follows: OT was significantly correlated with C2S ($r = -0.93$), C2-7 ($r = 0.71$), and T1S-CL ($r = -0.69$), but not with OI, C0-2, and T1S. C2S was significantly correlated with C0-2 ($r = 0.32$), C2-7 ($r = -0.69$), and T1S-CL ($r = 0.78$). There was no significant correlation between OI and the other parameters. C2-7 was significantly correlated with C2S ($r = -0.69$), OT ($r = 0.71$) and T1S-CL ($r = -0.57$). T1S was significantly correlated with C2-7 ($r = 0.6$) and T1S-CL ($r = 0.31$). T1S-CL was significantly correlated with C2S ($r = 0.78$), C2-7 ($r = -0.57$), OT ($r = -0.69$) and T1S ($r = 0.31$) (Fig. 3).

For the MRI data, we derived the following correlation results: The OT was significantly correlated with C2S ($r = -0.76$), C2-7 ($r = 0.56$), T1S ($r = 0.36$), and T1S-CL ($r = -0.37$), but not with OI and C0-2. C2S was significantly correlated with C0-2 ($r = 0.51$), C2-7 ($r = -0.74$), OI ($r = 0.38$), OT ($r = -0.76$), and T1S-CL ($r = 0.69$), but not with T1S. OI was significantly correlated with C2S ($r = 0.38$), C0-2 ($r = 0.47$), and T1S-CL ($r = 0.49$), but not with OT, C2-7, and T1S. C2-7 was significantly correlated with C2S ($r = -0.74$), OT ($r = 0.56$), C0-2 ($r = -0.37$), T1S ($r = 0.59$), and T1S-CL ($r = -0.7$), but not with OI. T1S was significantly correlated with C2-7 ($r = 0.59$) and OT ($r = 0.36$). T1S-CL was significantly correlated with C0-2

Table 2 Pairwise differences of cervical sagittal parameters between DR and MRI

Parameter	DR	MRI	Pairwise Difference	
	Mean (SD)	Mean (SD)	Mean (SD)	p value
OI (°)	15.38 (2.32)	16.68 (4.33)	-1.29 (4.38)	0.063
OT (°)	12.51 (6.18)	5.44 (6.51)	7.07 (7.39)	<0.001
C2S (°)	2.80 (6.36)	11.40 (6.83)	-8.60 (7.03)	<0.001
C0-2 (°)	24.60 (9.47)	15.03 (6.26)	9.57 (9.68)	<0.001
C2-7 (°)	20.76 (9.73)	12.24 (10)	8.52 (9.59)	<0.001
T1S (°)	31.71 (8.40)	28.37 (7.21)	3.34 (7.42)	0.006
T1S-CL (°)	10.95 (8.21)	16.13 (8.17)	-5.19 (7.95)	<0.001

DR digital radiography; MRI magnetic resonance imaging; OI odontoid incidence; OT odontoid tilt; C2S C2 slope; T1S T1 slope; CL cervical lordosis

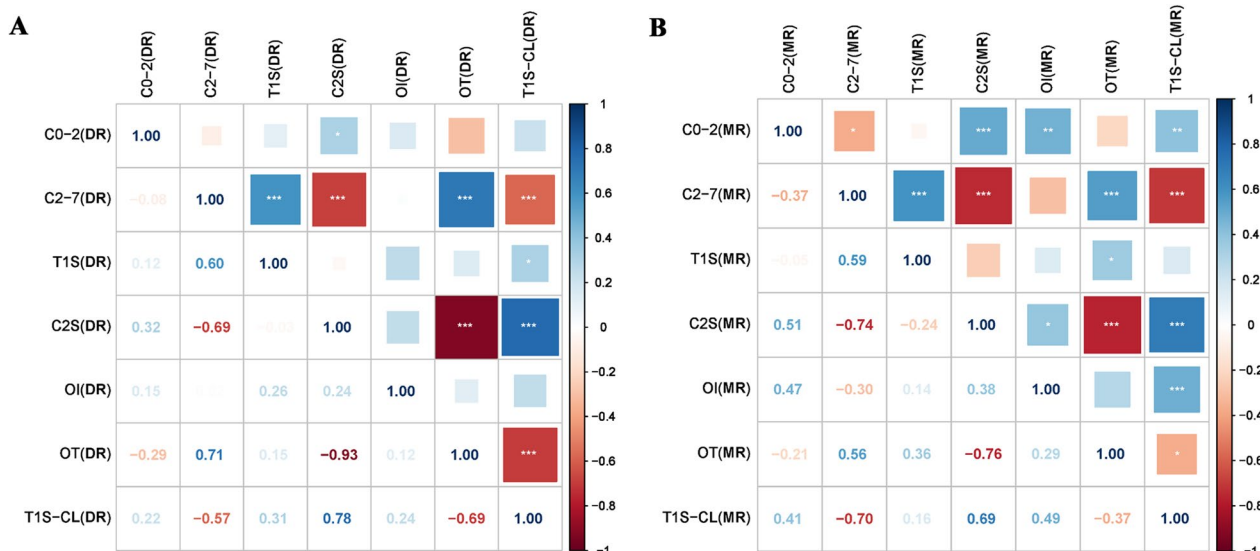


Fig. 3 Heat map of correlations. **A:** Pearson correlation analysis between OI, OT and cervical parameters on cervical DR images; **B:** Pearson correlation analysis between OI, OT and cervical parameters on cervical MRI images. OI odontoid incidence; OT odontoid tilt; DR digital radiography; MRI magnetic resonance imaging

($r=0.41$), OI ($r=0.49$), C2S ($r=0.78$), C2-7 ($r=-0.7$) and OT ($r=-0.37$), but not with T1S (Fig. 3).

Validation of formula efficacy

This study validated the efficacy of the formula $CL=0.36 \times OI - 0.67 \times OT - 0.69 \times T1S$ model on X-ray and MRI. The results showed a significant correlation between predictive value and observed value on X-ray and MRI. Specifically, the correlation coefficient (r) on X-ray was -0.862 with an R^2 value of 0.744 ; on MRI, the correlation coefficient (r) was -0.783 with an R^2 value of 0.614 (Fig. 4).

Discussion

In this study, the sagittal plane parameters of the cervical spine measured by X-ray and MRI showed good overall inter-observer agreement. They were also similarly accurate and reliable for determining the OI. This confirms that OI is independent and stable under the influence of external factors, which is consistent with the results of a previous study [9, 20, 21]. To maintain an overall sagittal balance of the cervical spine, an increase in the angles of C0-2 and T1S-CL is required. The results of this study showed that C2S on the X-ray was positively correlated with C0-2 and T1S-CL, while it was negatively correlated with C2-7. Furthermore, OT, C2-7, and T1S obtained from X-ray measurements had greater angles compared to those obtained from MRI, while C2S and T1S-CL had smaller angles. This difference may be due to the pressure exerted on the vertebrae by the weight of the skull during X-ray in the standing position, whereas the reaction force

of the bed has an effect on the vertebrae during MRI in the supine position. This is consistent with the results of a previous study [22], which found that skull contact with the table and applying a reaction force on the neck that projected posteriorly resulted in a decrease in the angle of rotation of the first thoracic vertebra, which resulted in a smaller T1S observed on MRI.

Unlike Lee’s study [9], the correlation between the OI and the C2S, C0-2, and T1S-CL is pronounced on MRI images in our study. There are several possible explanations for this discrepancy, which include the differences in the sagittal configuration of cervical spine between Chinese and Koreans, and the differences between MRI and EOS techniques. OI may be affected by the complex anatomy of the odontoid and the difficulty in stabilizing the odontoid tip since it rotates on its own between the anterior arch of the atlas and the transverse ligament of the atlas measurement [23, 24]. We found no significant correlation between C0-2 and OI, agrees exceptionally well with what Ames et al. have concluded in their study that smaller correlation coefficients for this parameter in close proximity to the head [25]. According to the research findings of Lee and his colleagues, other factors may contribute more to the overall alignment of the cervical spine, resulting in a moderate correlation coefficient, compared to the parameter of the odontoid process closest to the head [9]. This phenomenon may result from measurement error, anatomical differences, distinctions between imaging methods, or other unknown factors.

Previous studies have demonstrated that if the CL is not sufficient to match the patient’s given T1S, the

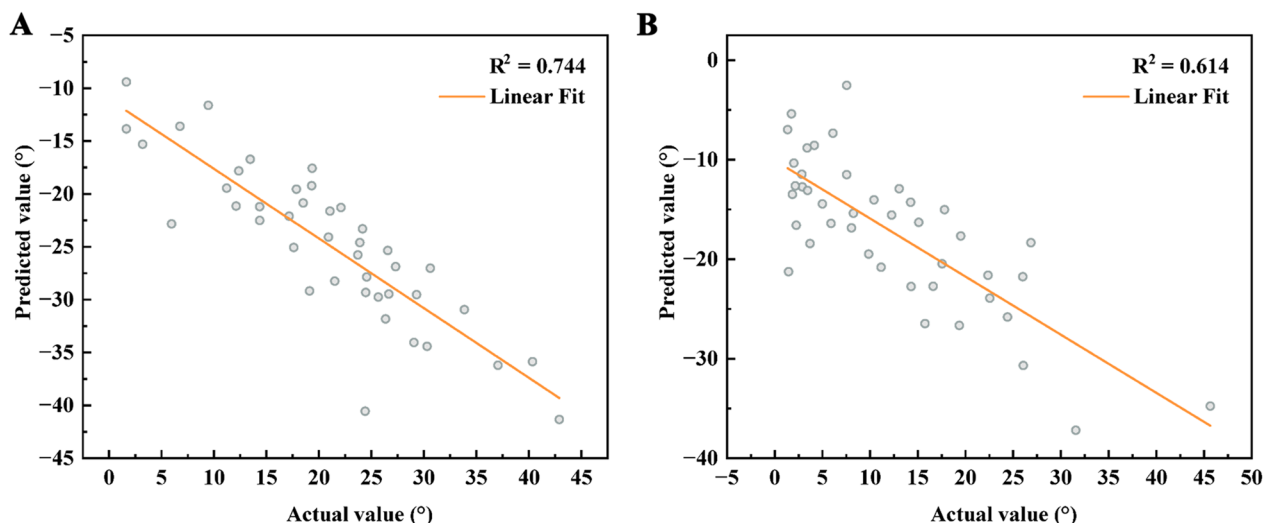


Fig. 4 Validation of CL prediction formula efficacy. **A:** Validation of CL prediction formula efficacy on DR images; **B:** Validation of CL prediction formula efficacy on MRI images. R^2 represents the coefficient of determination. CL cervical lordosis; DR digital radiography; MRI magnetic resonance imaging

second cervical vertebra will tilt forward to increase the C2S [26]. This suggests that OT decreases when the C2S angle increases, which is identical with the findings of Lee et al. [9]. These phenomena may reflect the structural interrelationships and physiological characteristics in the sagittal plane of the cervical spine. On MRI, OT was significantly correlated with C2S, C2-7, T1S, and T1S-CL, suggesting that OT may reveal the structural and positional relationships of the overall cervical spine. Specifically, a reduced OT angle may result in a forward tilt of C2S and C2-7 and a backward tilt of T1S and T1S-CL, thereby affecting the position and structure of the overall cervical spine. This study confirmed and validated the formula proposed by Lee et al. [9], for predicting the normative CL of a given patient: $CL = 0.36 \times OI - 0.67 \times OT - 0.69 \times T1S$. The formula predicts CL with a high predictive accuracy in X-ray and MRI applications. Not only does this formula possibly provide a threshold for cervical deformity, but it also implies a goal for surgical correction to reconstruct the predicted physiological cervical alignment.

This study has several limitations. First, it was a retrospective study with minor variations in the location of subjects on radiographic images, which may lead to selection bias. Second, the sample size was small and only healthy subjects were included, which may not be fully representative of the entire population. To reduce heterogeneity among participants, we only included the healthy subjects who exhibited no signs of degenerative disk changes. Some normal individuals with degenerative changes (disk height loss or osteophytes) were excluded in this study, which may also create a selection bias. Third, in our study, the accuracy of OI measurements on X-ray images might be limited because of a less clear depiction of the odontoid process on X-ray images than that on MRI images. This phenomenon may lead to a slight underestimation of ICC on X-ray in our study. Fourth, we could not further analyze some factors (gender, age, and disk height loss) that influence cervical sagittal balance. These potential confounders may exert an impact on the correlation between OI and cervical sagittal parameters, and consequently, may weaken the validity of the results. Thus the results need to be interpreted with caution.

Conclusion

In summary, OI was verified as a constant anatomic parameter, demonstrating the necessity of a combined assessment of cervical sagittal balance by employing standing X-ray and supine MRI. The formula $CL = 0.36 \times OI - 0.67 \times OT - 0.69 \times T1S$ can be used to predict CL in cervical sagittal parameters. This study has great significance in clinical applications, especially for

medical imaging specialists who need to be aware of the differences of measurements between standing X-ray and supine MRI when evaluating cervical sagittal balance.

Abbreviations

MRI	Magnetic resonance imaging
OI	Odontoid incidence
OT	Odontoid tilt
C2S	C2 slope
T1S	T1 slope
CL	Cervical lordosis
ICC	Intraclass correlation coefficient
CI	Confidence intervals
HRQOL	Health-related quality of life

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None.

Author contribution

Conceptualization: JH; Data curation: HLA; Formal analysis: HLA, QHY; Methodology: HLA, XHY; Project administration: JH, CWY; Visualization: HLA; Writing—original draft: HLA; Writing—review and editing: JH.

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Availability of data and materials

The data used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate

The study has been approved by the Medical Ethics Committee of the First Affiliated Hospital of Guangxi Medical University (2023-E008-01).

Competing interests

The authors have no conflicts of interest to declare in relation to this article.

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