Reproducibility of cervical sagittal alignment parameters including C2 slope in cervical spondylotic myeloradiculopathy.

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Reproducibility of cervical sagittal alignment parameters including C2 slope in cervical spondylotic myeloradiculopathy.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

Reproducibility of cervical sagittal alignment parameters including C2 slope in cervical spondylotic myeloradiculopathy.

As the importance of the sagittal alignment of the cervical spine has emerged, many radiological parameters have been proposed and evaluated for their usefulness in assessing the cervical sagittal alignment. The C2 slope is a parameter that can reflect the cervical sagittal alignment. Since there are few interferential factors impacting C2 slope measurements, it can be used as an explicit attribute derived from lateral cervical radiographs.

This study aimed to analyze the clinical usefulness of the C2 slope as an indicator of cervical sagittal alignment by comparing the reproducibility of C2 slope measurements to that of other established radiographic parameters reflecting this alignment in cervical spondylotic myeloradiculopathy patients.

A retrospective, nonrandomized study of diagnostic X-ray images was conducted. These images had been acquired as part of a routine clinical protocol for eligible patients examined at our hospital between 2017 and 2021.

A total of 79 patients with cervical spondylotic myeloradiculopathy who underwent multilevel cervical spine fusion and 79 control participants were included in this study.
C2 slope, the cervical sagittal vertical axis (cSVA), C2–7 Cobb angle, T1 slope, and T1 slope – cervical lordosis (T1S-CL) were measured. The intra-observer and inter-observer correlation coefficients (ICC) were employed to assess intra-observer and inter-observer reproducibility, using the Bland–Altman plot to detect systemic errors by comparing pairs of observers.

All intra- and inter-observer correlation coefficient values in the spondylotic myeloradiculopathy patient group and the control participant group were found to be 0.75 or higher, showing excellent reproducibility. The ICC value of the C2 slope was significantly higher than that of all other parameters.

The measurement of the C2 slope has high reproducibility compared to other parameters regardless of interferential factors. It can be a suitable parameter for measuring the cervical sagittal alignment before and after multilevel cervical spine surgery in cervical spondylotic myeloradiculopathy patients.

Key words :cervical spine, C2 slope, cervical lordosis, cervical sagittal vertical axis (cSVA), T1 slope, sagittal alignment

1. INTRODUCTION

The cervical spine not only supports the head (average weight: 4.5 kg) but also has the broadest range of motion among the spine.[1] The cervical spine forms a lordotic curvature combined with a solid kyphotic curvature of the thoracic inlet at the border of the distal cervicothoracic junction. If this alignment becomes abnormal and the lordotic curvature of the cervical spine decreases or changes to kyphotic curvature, it causes pain and disability. In addition, the cervical spine plays an important role in influencing the alignment of the spine below the cervical spine and pelvic tilt to maintain a horizontal gaze.[2]

Understanding the cervical sagittal alignment is essential for spinal surgeons because it significantly affects the clinical outcomes of surgery. Sagittal alignment of the cervical spine is also critical in determining the surgical approach or instrumentation level and predicting the postoperative prognosis (adjacent segmentation disease).[3] As the importance of sagittal alignment of the cervical spine emerges, many radiological parameters have been proposed for evaluating the cervical sagittal alignment.

Traditionally, the C2-C7 Cobb angle has been widely used to assess cervical sagittal alignment. The Cobb angle has been commonly used because it is the easiest to measure and has high inter- and intra-observer reproducibility. However, it is generally known that the C2-C7 Cobb angle is underutilized.[4] Recently established concepts such as T1 slope and T1 slope–cervical lordosis are also considered essential parameters.[5] Although these newer parameters have been demonstrated in many studies, accurate measurement of the T1 slope is generally not easy in patients with short necks or muscularity due to interference from shoulder shading.[6] The cervical sagittal vertical axis, that is used as a parameter indicating the sagittal balance of the cervical spine, is also not easy to measure accurately for the reasons described above..

The C2 slope represents a recently introduced parameter that can be used as an unequivocal indicator of the cervical sagittal alignment.[7] The C2 slope can be measured from the lateral cervical radiograph with little interference during measurement.[8] This study aimed to analyze the clinical usefulness of the C2 slope by comparing its reproducibility to that of other established radiographic parameters used to assess the cervical sagittal alignment in cervical spondylotic myeloradiculopathy patients.

2. MATERIALS AND METHODS

2.1 Patients

After approval by the Institutional Review Board (Approval Number 2022-0841-001), patients diagnosed with severe cervical spondylotic myeloradiculopathy requiring more than three levels of cervical fusion surgery between 2017 and 2021 were retrospectively identified. The gender and age of patients were reviewed. Cases of trauma, tumor, and infection were excluded. All the patients had multiple-level cord compression and foraminal stenosis with disc height loss. To eliminate these lesions, the patients underwent staged combined anterior and posterior cervical spine fusion surgery. Those patients who had undergone surgery for factors other than degenerative lesions such as infection, tumors, and trauma, patients with less than three-level fusion, and patients with only anterior or posterior fusion were excluded from this study.

2.2 Control group

Control participants were randomly selected from the imaging database of the institution. The participants were matched for age and gender. The reason for setting up a control group was to determine the differences in reproducibility of measuring cervical alignment parameters between the normal group and the patient group presenting with cervical malalignment and degenerative abnormalities, such as disc height loss, anterior osteophyte, posterior osteophyte, uncovertebral arthritis, endplate sclerosis, facet joint osteoarthritis, and implants. Control participants presenting with spinal deformity in the frontal or sagittal plane, transitional anomaly, spondylolisthesis, and degenerative abnormalities were excluded from this study.

2.3 Radiologic evaluation

Neutral lateral plain radiographs were obtained in the standing position. The following parameters were measured using the Centricity Web (Enterprise Web ver. 3.0; GE Healthcare, Chicago, IL, USA) picture archiving and communication system. The C2 slope, cervical sagittal vertical axis (cSVA), C2–7 Cobb angle, T1 slope, and T1 slope–cervical lordosis (T1S-CL) were measured. The C7 slope was measured in three patients whose T1 was not shown on plain radiographs.[6] Our study compared and analyzed the reproducibility of measuring various parameters of the cervical alignment preoperatively (last preoperative outpatient visit) and postoperatively (postoperative day-1) in patients with cervical spondylotic myeloradiculopathy. Additionally, the same study was conducted in the control group while excluding measurement interference factors such as degenerative abnormalities that should be considered when measuring such parameters. The reproducibility in measuring various control group parameters was also compared and analyzed. When needed, variations in contrast and luminosity helped to reveal the bone landmarks optimally. The radiographic measurements were defined as follows:

(1) C2 slope: The angle between the lower endplate of C2 and the horizontal plane [7]
(2) cSVA: The distance between the C2 plumb line and the superior posterior endplate of C7 [9]
(3) C2-7 Cobb angle: The angle between the lower endplates of C2 and C7 [10]
(4) T1 slope: The angle between the upper endplate of T1 and the horizontal plane [11]
(5) T1S-CL: The angle of T1S minus C2-7 Cobb angle [5]

Three independent observers measured the patient group twice (1st, 2nd) at 2-week intervals for radiographs taken before and after surgery, and twice at 2-week intervals for the control group. (total: 7,110 measurements). One of the three observers was a junior (novice) spine surgeon and two were spine surgery fellows in training. Three observers used three neutral lateral radiographs for common training and those radiographs were then excluded from the study. Each observer recorded the angles and distances for each patient. The following spinal parameters were measured (Figure 1).

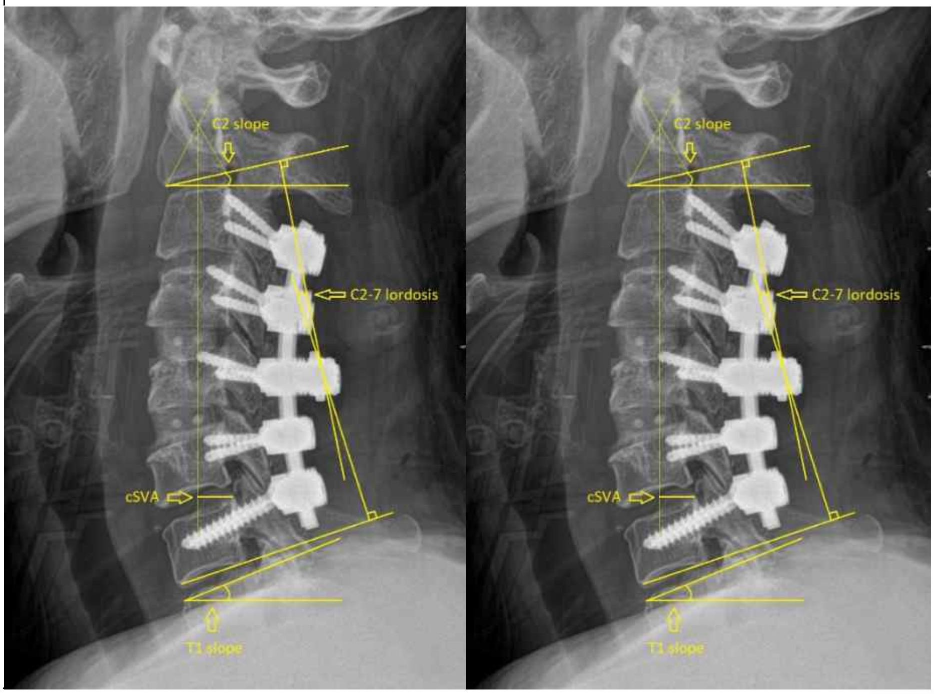


Figure 1. Preoperative and postoperative neutral lateral plain radiographs representing the cervical sagittal alignment parameters in a patient

2.4 Sample size

The number of participants required for this study was calculated by a Power calculation using PASS software (version 15, NCSS, LLC. Kaysville, Utah, USA).[12] The inter- and intra-observer correlation coefficient (ICC) of the C2 slope assumes a minimum value of 0.85, which is the ICC of the reference radiograph.[13] The minimum ICC value for the reference radiograph was measured and found to be 0.75: it was assumed that if the ICC of the C2 slope was greater than 0.75 then this would signify excellent reproducibility. ICC was measured twice by three observers. The ICC value for measurements made by three observers denotes an inter-observer correlation coefficient while the ICC value for two measurements made by one observer denotes an intra-observer correlation coefficient. Assuming that the ICC of the C2 slope is higher than 0.75, the number of observers is three, the significance level is 0.05, the power calculation significance is 80%, we

calculated that our study would require a sample size of 54 participants. Since the ICC analyzes the control and patient groups (pre- and postoperatively), we calculated that a total of 108 participants would be required in our study (54 participants per group). Assuming the same conditions and keeping the intra-observer measurement number at two, we calculated that our study would then require a total of 158 participants (79 per group). Therefore, we estimated that our study required 79 people per group to analyze both the inter- and intra-observer ICC (Table 1)
.

Table1. Sample size calculations extracted using PASS (version 15, NCSS, LLC. Kaysville, Utah, USA)

	1-β(power)[1,7]	α^6	k[3]	ρ_0[4]	ρ_1[5]	Total N[2]
Inter-observer	0.8	0.05	3	0.75	0.85	54
Intra-observer	0.8	0.05	2	0.75	0.85	79

[1]Power is the probability of rejecting a false null hypothesis. It should be close to one.
[2]N is the number of subjects.
[3]K is the number of observations per subject in the sample.
[4]ρ0 is intra-observer correlation assuming the null hypothesis.
[5]ρ1 is intra-observer correlation assuming the alternative hypothesis.
[6]Alpha is the probability of rejecting a true null hypothesis. It should be small.
[7]Beta is the probability of accepting a false null hypothesis. It should be small.

2.5 Statistical analysis

Statistical analyses were performed using SAS version 9.4 (SAS Institute, Cary, NC, USA) and R statistics 4.1.3 (http://www.r-project.org). The intra-observer and inter-observer ICC values were used to assess intra-observer and inter-observer reproducibility by using the Bland–Altman plot for the detection of systemic errors, comparing pairs of observers. According to Rosner et al.[14], an ICC value of less than 0.40 indicates poor reproducibility, values in the range of 0.40–0.75 indicate fair to good reproducibility, and values greater than 0.75 show excellent reproducibility. We analyzed the intra-observer ICC values by checking the consistency of the resulting values at each point in time (1st, 2nd): when all three observer values are considered and when only one observer value is considered. The ICC of the five measures was compared using the bootstrapping method to calculate p-values.

3. RESULTS

3.1 Demographic results

The average age of the control group participants was 62.3 years. The gender ratio of the control group participants was 56 women vs. 23 men. The mean age of the patient group was 63.7 years. The gender ratio of the patients was 55 women for 24 men) No significant differences in demographic data were noted between the two groups.

3.2 Radiographic results

The interobserver reproducibility in the control group is summarized in Table 2. In the first and second measurements, there was a statistically significant difference in the ICC between the C2 slope and all the remaining parameters. In the first measurement, there was no significant difference between the C2 slope with SVA and C2-7 lordosis, but the ICC values were 0.969, 0.948, and 0.907, respectively, showing high ICC values for the C2 slope. The same results were obtained when both the first and second measurements were included.

Table 2. Comparison of Inter-observer correlation coefficient in control group among the three observers.

Time of measurement	Observer	C2 slope (1)	T1 slope (2)	cSVA (3)	C2-7 lordosis (4)	T1S-CL (5)	Pairwise comparison p-value			
		ICC (95% CI)	ICC (95% CI)	ICC (95% CI)	ICC (95% CI)	ICC (95% CI)	1 vs 2	1 vs 3	1 vs 4	1 vs 5

Total (1st+2nd)	Observer 1, 2, 3	0.963 (0.952-0.973)	0.842 (0.812-0.873)	0.922 (0.898-0.946)	0.887 (0.83-0.944)	0.777 (0.691-0.862)	<.0001*	0.001*	0.0072*	<.0001*
1st	Observer 1, 2, 3	0.969 (0.957-0.982)	0.864 (0.826-0.903)	0.948 (0.925-0.971)	0.907 (0.833-0.98)	0.784 (0.659-0.91)	<.0001*	0.0883	0.0815	0.0026*
2nd	Observer 1, 2, 3	0.957 (0.939-0.974)	0.825 (0.774-0.876)	0.896 (0.852-0.939)	0.867 (0.778-0.956)	0.771 (0.659-0.883)	<.0001*	0.0088*	0.0435*	0.0008*

* p–value ≤ 0.05.

The intraobserver reproducibility in the control group is shown in Table 3. In the first and second measurements for each observer, the ICC values between the C2 slope and the remaining parameters showed significant differences. In the third observer, there was no significant difference between the C2 slope and C2-7 lordosis. However, the ICC values were 0.99 and 0.984, respectively, showing a high C2 slope. The same result was obtained when all three observers were included.

Table 3. Comparison of Intra-observer correlation coefficient in control group for each observer and among the three observers

Observer	Time of measurement	C2 slope (1)	T1 slope (2)	cSVA (3)	C2-7 lordosis (4)	T1S-CL (5)	Pairwise comparison p-value			
		ICC (95% CI)	ICC (95% CI)	ICC (95% CI)	ICC (95% CI)	ICC (95% CI)	1 vs 2	1 vs 3	1 vs 4	1 vs 5
Observer 1, 2, 3	1st, 2nd	0.988 (0.985-0.991)	0.915 (0.898-0.931)	0.972 (0.964-0.979)	0.962 (0.949-0.975)	0.904 (0.875-0.934)	<.0001*	<.0001*	0.0002*	<.0001*
Observer 1		0.982 (0.974-0.99)	0.877 (0.843-0.912)	0.958 (0.94-0.976)	0.929 (0.892-0.967)	0.825 (0.745-0.905)	<.0001*	0.0196*	0.0094*	0.0001*
Observer 2		0.992 (0.988-0.995)	0.912 (0.878-0.946)	0.98 (0.97-0.99)	0.976 (0.965-0.988)	0.937 (0.903-0.971)	<.0001*	0.0196*	0.0077*	0.001*

Observer 3	0.99 (0.986-0.994)	0.956 (0.941-0.972)	0.978 (0.969-0.988)	0.984 (0.976-0.992)	0.944 (0.927-0.961)	<.0001*	0.0146*	0.1569	<.0001*

* p–value ≤ 0.05.

The interobserver reproducibility in the preoperative group is summarized in Table 4. In the first and second measurements, there was a statistically significant difference in the ICC between the C2 slope and all the remaining parameters. In the first measurement, there was no significant difference between C2 slope with SVA and C2-7 lordosis, but the ICC values were 0.961, 0.938, and 0.807, respectively, showing high ICC values for the C2 slope. In the second measurement, there was no significant difference between the C2 slope with SVA and C2-7 lordosis, but the ICC values were 0.968, 0.964, and 0.913, respectively, showing high ICC values for the C2 slope. The same results were obtained when both the first and second measurements were included.

Table 4. Comparison of Inter-observer correlation coefficient in preoperative patient group among the three observers

Time of measurement	Observer	C2 slope (1)	T1 slope (2)	cSVA (3)	C2-7 lordosis (4)	T1S-CL (5)	Pairwise comparison p-value			
		ICC (95% CI)	ICC (95% CI)	ICC (95% CI)	ICC (95% CI)	ICC (95% CI)	1 vs 2	1 vs 3	1 vs 4	1 vs 5
Total (1st+2nd)	Observer 1, 2, 3	0.964 (0.945-0.983)	0.88 (0.844-0.916)	0.951 (0.935-0.967)	0.857 (0.755-0.96)	0.808 (0.708-0.908)	<.0001*	0.214	0.041*	0.0015*
1st	Observer 1, 2, 3	0.961 (0.929-0.993)	0.873 (0.819-0.926)	0.938 (0.907-0.97)	0.807 (0.635-0.979)	0.758 (0.554-0.923)	0.006*	0.2488	0.0768	0.014*
2nd	Observer 1, 2, 3	0.968 (0.943-0.993)	0.889 (0.839-0.938)	0.964 (0.948-0.981)	0.913 (0.832-0.994)	0.867 (0.785-0.949)	0.0048*	0.783	0.1822	0.0086*

* p–value ≤ 0.05.

Intraobserver reproducibility in the preoperative group is summarized in Table 5. Although significant differences in the ICC were less than those in the control group, the ICC values between the C2 slope and the remaining parameters in the first and second measurements of each observer showed significant differences, as did the control group.

Table 5. Comparison of Intra-observer correlation coefficient in preoperative patient group for each observer and among the three observers

Observer	Time of measurement	C2 slope (1)	T1 slope (2)	cSVA (3)	C2-7 lordosis (4)	T1S-CL (5)	Pairwise comparison p-value			
		ICC (95% CI)	ICC (95% CI)	ICC (95% CI)	ICC (95% CI)	ICC (95% CI)	1 vs 2	1 vs 3	1 vs 4	1 vs 5
Observer 1, 2, 3	1st, 2nd	0.982 (0.971-0.993)	0.91 (0.884-0.936)	0.968 (0.959-0.976)	0.837 (0.714-0.96)	0.792 (0.678-0.907)	<.0001*	0.0231	0.0205*	0.001*
Observer 1	1st, 2nd	0.973 (0.94-1.006)	0.873 (0.809-0.937)	0.951 (0.927-0.975)	0.754 (0.458-0.989)	0.766 (0.416-0.916)	0.0064*	0.2710	0.0645	0.0142*
Observer 2	1st, 2nd	0.985 (0.976-0.994)	0.926 (0.892-0.959)	0.979 (0.97-0.988)	0.975 (0.964-0.986)	0.928 (0.895-0.96)	0.0010*	0.2537	0.1043	0.0003*
Observer 3	1st, 2nd	0.99 (0.984-0.996)	0.937 (0.908-0.967)	0.975 (0.964-0.986)	0.822 (0.584-1.059)	0.757 (0.5-1.014)	0.0006*	0.0087*	0.1654	0.0744

* p–value ≤ 0.05.

The interobserver reproducibility in the postoperative group is summarized in Table 6. In the first and second measurements, there was a statistically significant difference in the ICC between the C2 slope and all the remaining parameters. In the second measurement, there was no significant difference between the C2 slope with SVA and C2-7 lordosis, but the ICC values were 0.968, 0.94, and 0.926, respectively, showing high ICC values for the C2 slope. The same results were obtained when both the first and second measurements were included.

Table 6. Comparison of Inter-observer correlation coefficient in postoperative patient group among the three observers

Time of measurement	Observer	C2 slope (1)	T1 slope (2)	cSVA (3)	C2-7 lordosis (4)	T1S-CL (5)	Pairwise comparison p-value			
		ICC (95% CI)	ICC (95% CI)	ICC (95% CI)	ICC (95% CI)	ICC (95% CI)	1 vs 2	1 vs 3	1 vs 4	1 vs 5
Total (1st+2nd)	Observer 1, 2, 3	0.964 (0.946-0.981)	0.848 (0.808-0.887)	0.911 (0.878-0.945)	0.915 (0.886-0.943)	0.767 (0.707-0.827)	<.0001*	0.0003*	0.0024*	<.0001*
1st	Observer 1, 2, 3	0.959 (0.928-0.99)	0.876 (0.838-0.915)	0.884 (0.826-0.942)	0.905 (0.86-0.95)	0.793 (0.721-0.866)	0.0011*	0.0012*	0.0377*	<.0001*
2nd	Observer 1, 2, 3	0.968 (0.949-0.987)	0.82 (0.749-0.892)	0.94 (0.913-0.967)	0.926 (0.886-0.965)	0.743 (0.653-0.833)	0.0001*	0.0832	0.0505	<.0001*

* p–value ≤ 0.05.

Intraobserver reproducibility in the postoperative group is summarized in Table 7. Although significant differences in ICC were less than those in the control and preoperative groups, the ICC values between the C2 slope and the remaining parameters in the first and second measurements of each observer showed significant differences, as did those in the control and preoperative groups.

Table 7. Comparison of Intra-observer correlation coefficient in postoperative patient group for each observer and among the three observers

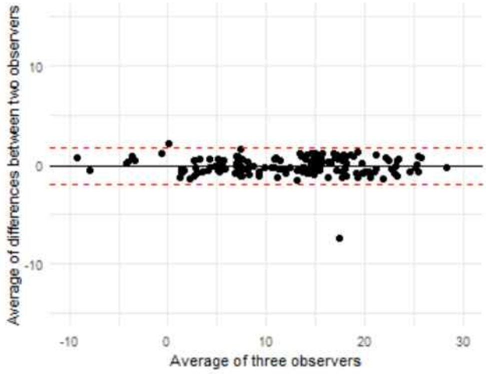
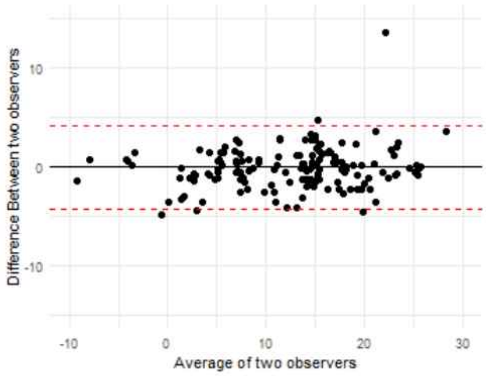
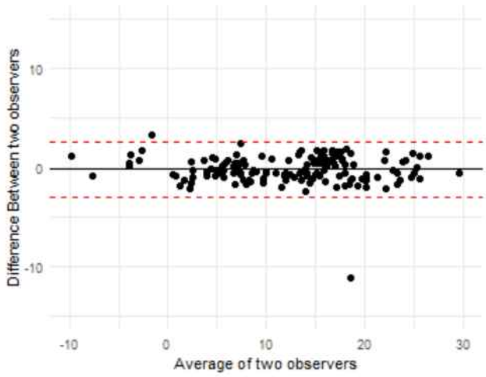
observer	Time of measurement	C2 slope (1)	T1 slope (2)	cSVA (3)	C2-7 lordosis (4)	T1S-CL (5)	Pairwise comparison p-value			
		ICC (95% CI)	ICC (95% CI)	ICC (95% CI)	ICC (95% CI)	ICC (95% CI)	1 vs 2	1 vs 3	1 vs 4	1 vs 5
Observer	1st, 2nd	0.969	0.919	0.955	0.949	0.887	0.000	0.105	0.054	<.000

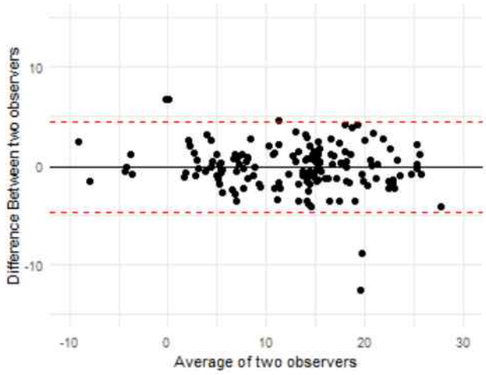
1, 2, 3	(0.954-0.984)	(0.897-0.941)	(0.933-0.977)	(0.934-0.964)	(0.858-0.916)	2*	7	9	1*
Observer 1	0.988 (0.983-0.993)	0.934 (0.894-0.973)	0.974 (0.961-0.988)	0.955 (0.929-0.982)	0.894 (0.841-0.947)	0.0075*	0.0567	0.015*	0.0004*
Observer 2	0.96 (0.919-1.001)	0.942 (0.921-0.963)	0.926 (0.856-0.996)	0.93 (0.897-0.962)	0.919 (0.888-0.949)	0.4461	0.1139	0.2045	0.0866
Observer 3	0.959 (0.931-0.988)	0.874 (0.814-0.934)	0.956 (0.934-0.979)	0.96 (0.936-0.984)	0.848 (0.782-0.914)	0.0117*	0.867	0.9719	0.0004*

* p–value ≤ 0.05.

The Bland-Altman plot analysis revealed the difference between the two observers with respect to their average angle or distance on the same radiograph. A point between the +2 SD and -2SD lines was considered an indication of good observer consensus. The Bland–Altman plot is a graph for checking the match of two people, so there is no standardized method to express the match of three people. Therefore, the x-axis represents the average of the values of the three observers, and the y-axis represents the average of the values of the differences between the two observers (=((Observer1-2)+(Obsever1-3)+(Observer2-3))/3). When reviewed by pairs of observers, this analysis showed no systemic errors between intra- and inter-observers. An example is shown in Table 8.

Table 8. Bland–Altman plots graph for Value of C2-slope between inter-observers in postoperative patient. No major differences and excellent inter-observer reproducibility was observed.

Time of measurement	observer	C2-slope
Total (1st+2nd)	observer 1, 2, 3	
	observer 1, 2	
	observer 1, 3	

Time of measurement	observer	C2-slope
	observer 2, 3	

4. DISCUSSION

Despite its severity, cervical sagittal malalignment has been under studied and less well characterized than thoracolumbar sagittal malalignment.[15] However, several parameters have recently been introduced in addition to the traditional cervical sagittal alignment parameters. We measured some of the most common and well-validated parameters of cervical sagittal alignment, including C2 slope, cervical sagittal vertical axis, C2-C7 Cobb Angle, T1 slope, and T1 slope minus C2-C7 lordosis. To our knowledge, no comparative reproducibility study has been conducted on the radiological parameters of cervical sagittal alignment.

The C2 slope has recently been proposed as a single, simplified measure of cervical deformity approximating the T1S-CL measure.[8] It has been suggested that the C2 slope adequately describes cervical deformity due to its intimate connections with the occipitocervical and cervicothoracic spine. Mathematically, the following was considered: TS-CL = T1 slope - (C7 slope - C2 slope). In many patients, the T1 and C7 slopes are approximately equal, meaning that they cancel out in the equation, leaving the C2 slope as the sole variable for measuring the deformity. In instances where the T1 and C7 slopes

are approximately equal, the C2 slope can be obtained by drawing a line parallel to the C2 lower endplate and taking the angle between this line and the horizontal plane. Although data on "normal" C2 slope were insufficient, Iyer et al. reported an average T1S of 26.1°±9° and a cervical lordosis of -12..2°±13.6°, resulting in a T1S-CL value of 13.9° in the cohort of normal asymptomatic adults.[16] Staub et al. reported a standard T1S-CL value of 16.5°. Because the C2 slope is an approximation of the T1S-CL, therefore the normal C2 slope value can be assumed to be close to this value.[7] Other studies have pointed out that the C2 slope assumes a value near 15° for a comfortable horizontal gaze because occiput to C2 lordosis is 30° in asymptomatic adults in a standing posture.[1] Kim et al. reported that the C2 slope had cut-off points of 18.8°, 22.25°, and 25.35° according to a cSVA of 40 mm.[8] In this study, the C2 slope of the control group was 16.93°, that of the preoperative group was 21.37°, and that of the postoperative group was 15.67°. The ICC value of the C2 slope was much higher than that of all the other parameters. The only X-ray landmark required to measure the C2 slope was the C2 lower endplate line and the horizontal line. In the case of C2 slope measurement, it is free of measurement interference factors such as osteophyte, uncovertebral hypertrophy, endplate sclerosis, bone graft, and posterior implant. Therefore, it is believed that both the intraobserver and interobserver values were the highest. In addition, in patients with short necks or large shoulder muscles, the lower-level cervical is not easily visible, while the upper-level cervical is clearly visible without adjusting shade, and so it is expected to have a high ICC value.

The cervical sagittal alignment was measured using the cervical sagittal vertical axis (cSVA) parameter. The actual global cSVA represents the distance between the plumb line lowered from the center of gravity (COG) of the head and the posterior edge of the sacrum. However, since the COG cannot be represented by radiographs, therefore the distance between the C2 plumb line or C7 plumb line and the posterior edge of the sacrum is referred to as C2 SVA and C7 SVA, respectively, indicating the sagittal alignment of the entire spine. The COG is said to correspond roughly to the front of the external ear canal. The regional implication of the cervical vertebrae SVA is the distance from the center of the C2 (or odontoid process) to the posterior edge of C7.[2] In contrast to the wide range described previously for normal angles of cervical lordosis, cervical sagittal balance, measured by cSVA, has classically been described as having a much narrower range. For example, Hardacker et al. determined that the C2-C7 SVA in standing asymptomatic volunteers was approximately 16.8 + 11.2 mm.[9] In this study, the cSVA value of the control group was 16.29 mm, that of the preoperative group was 20.5 mm, and that of the postoperative group was 17.62 mm. The ICC of the cSVA showed the highest value after C2 slope. These results are thought to be due to the clear observation of the center of the C2 vertebral body and the posterosuperior corner of the C7 vertebral body in the radiographs of most patients.

Sagittal alignment can vary in the normal cervical spine and a lordotic curvature between 20-35 degrees is typically maintained. Yukawa et al. reported the use of C2-C7 Cobb angle measurements to determine the degree of C2-C7 cervical lordosis in a population of 1,200 asymptomatic patients, and found that the average C2-C7 lordosis was 13.9° ± 12.3°.[17] Gore et al. reported that the normal C2-C7 angle was determined to be 23° using the Jackson physiological stress line method in asymptomatic adults without local kyphosis.[18] Harrison et al. compared various measures of cervical sagittal alignment, including the C1-C7 and C2-C7 Cobb angles and the Harrison posterior tangent method, and reported that all measures had high inter- and intra-class correlations.[19] Interestingly, this study also found that the C2-C7 Cobb angle may be under measured because of the orientation of the inferior C2 endplate. In our study, the value of C2-C7 Cobb angle of the control group was 12.37°, the value of preoperative group was 5.79° and the value of postoperative group was 15.32°.

The T1 slope was analogous to the sacral slope. Just as greater pelvic incidence requires more lumbar lordosis to compensate for it, similarly individuals with a larger T1 slope also need more cervical lordosis to balance their heads over the thoracic inlet.[20] T1 slope – CL has also been considered an essential parameter. Although the usefulness of the above radiological parameters has been proven in many previous reports, accurate measurement of T1 values is not straightforward in the case of many patients because of their short necks or obstruction of shoulder shading.[6] Therefore, there is a fundamental limit to the application of these cervical parameters in all patients. In this study, the average values of the T1 slope were 25.65 in the control group, 20.27 in the preoperative group, and 27.91 in the postoperative group. C2-7 Cobb angle, T1 slope, and T1 slope - CL showed relatively lower ICC values than C2 slope or cSVA. These results may have been influenced by the neck length or shoulder shading of the participants, as mentioned above. In addition, preoperative factors, such as abnormal bony structures and osteophytes, and postoperative factors, such as bone graft and posterior implants, are also expected to be additional hurdles.

All images were analyzed using a simple and widely available numerical imaging software (Centricity Web) installed on computers in the institution. This software is currently used to analyze conventional radiographs and measure angles and distances. The reproducibility of the results found in this study indicates that it is possible to reliably use a straightforward numerical imaging tool to measure cervical sagittal alignment parameters.

ICC values were used to analyze data from three different observers using a sufficiently powerful and adaptive statistical tool. The Bland–Altman plot was used as a graphical approach, allowing direct visualization of agreement between observers according to the measured value. This method can accurately identify intra- and inter-observer biases when an observer systematically overestimates the measure, which other simple statistical tests cannot detect. Five parameters measured on 79 participants of each group by three observers were analyzed with two-by-two Bland–Altman plots: we made over 100 graphs, and it was decided to only show representative plots since the results of all the plots are almost the same.

The interference factors impacting the measurement of the cervical alignment parameters from lateral plane radiographs include anterior osteophytes, posterior osteophytes, uncovertebral osteoarthritis, endplate sclerosis, facet joint arthritis, bone graft, and posterior implantation.[21] One may ask whether interference factors could influence reproducibility, leading to the misplacement of bony landmarks on the vertebrae in a lateral view. However, excellent intra- and inter-observer reproducibility with ICC values above 0.75 were found for all sagittal parameters in all groups.[14] These results indicate that the interference factors can cause differences in the ICC values between the parameters but do not significantly affect reproducibility.

The limitations of this study are its retrospective nature and single-center design. Second, the image quality of the X-rays used was not uniform. There may have been some measurement bias because all radiographs were not acquired by the same radiological technologist, nor were they taken at the same time and angle. Third, when the surroundings of C7 and T1 were not clearly visible, the angle was measured by adjusting the shading. In such cases, it became difficult to express an accurate value compared to the value measured at the upper level, and there is a possibility that this may have caused some inter-observer bias. Nevertheless, all ICC values in all groups were 0.75 or higher, indicating excellent reproducibility. In future, our data are expected to help evaluate and predict the outcome of surgery by checking the C2 slope through portable X-rays taken in the operating room as well as X-rays taken before and after surgery to recover the cervical sagittal alignment and produce good surgical results.

5. CONCLUSION

The measurement of the C2 slope has high reproducibility compared to other parameters regardless of interferential factors, and it can be an unequivocal indicator of cervical alignment before and after multilevel cervical spine surgery in patients with cervical spondylotic myeloradiculopathy.

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Abstract in Korean

경추증성 척수신경근병증 환자의 C2 기울기를 포함한 경추 시상정렬을 나타내는 지표의 재현성

경추의 시상면 정렬의 중요성이 부각됨에 따라 경추의 시상면 정렬을 평가하는데 유용한 많은 방사선학적 지표가 제안되고 연구되고 있습니다. C2 기울기는 경추 시상면 정렬을 효과적으로 반영할 수 있는 지표입니다. C2 경사 측정에 영향을 미치는 간섭 요인이 거의 없기 때문에 측면 경추 방사선 사진에서 뚜렷한 영상을 얻을 수 있습니다.

본 연구의 목적은 경추 척추증성 척수신경근병증 환자에서 C2 경사 측정의 재현성을 다른 확립된 방사선학적 지표들의 재현성과 비교함으로써 경추 시상면 정렬의 지표로서 C2 경사의 임상적 유용성을 분석하는 것을 목표로 했습니다.

본 연구에는 다단계 경추 유합술을 받은 경추 척추증성 척수신경근병증 환자 총 79명과 대조군 참가자 79명이 포함되었습니다.

C2 경사, 경추 시상 수직축(cSVA), C2-7 Cobb 각도, T1 경사, T1 경사 - 경추 전만(T1S-CL)을 측정했습니다. 관찰자 내 및 관찰자 간 상관 계수(ICC)를 사용하여 관찰자 내 및 관찰자 간 재현성을 평가했습니다. 관찰자 쌍을 비교하여 시스템 오류를 탐지하기 위해 Bland-Altman Plot을 사용했습니다.

환자군과 대조군 모두 관찰자 내, 관찰자 간 상관계수 값이 0.75 이상으로 우수한 재현성을 보였습니다. C2 기울기의 ICC 값은 다른 모든 지표들의 ICC 값보다 높았습니다.

C2 기울기 측정은 간섭 요인에 관계없이 다른 지표들에 비해 높은 재현성을 갖습니다. 이는 경추 척추증성 척수신경근병증 환자의 다분절 경추 수술 전 후의 경추 시상면 정렬을 측정하는데 적합한 지표가 될 수 있겠습니다.

핵심되는 말 : 경추, C2 경사, 경추 전만증, 경추 시상 수직 축(cSVA), T1 경사, 시상 정렬