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ORIGINAL ARTICLE

Inter-spinous process distance: a novel parameter predicting segmental lordosis during posterior cervical spine deformity surgery

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Abstract

Purpose To investigate the normative value of distance between the spinous processes (inter-spinous process distance, ISPD), correlations between patients' demographics and ISPD, and determine cutoff ISPD values that result in segmental lordosis in posterior cervical-thoracic arthrodesis with instrumentation.

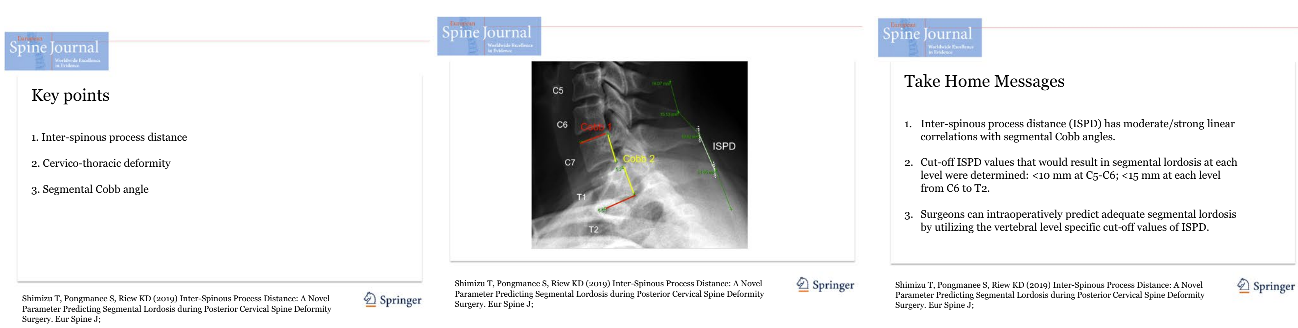
Methods We reviewed patients with visible lower cervical and cervicothoracic spinous processes (C5-T2) on dynamic X-rays. Radiographic measurements included segmental Cobb angles (S-Cobb) and ISPD, defined as the distance between midpoints of the spinous processes. Correlations between patient demographics and ISPD were evaluated. In addition, the cutoff ISPD values that predict segmental lordosis (S-Cobb < 0°) were determined using the receiver operating characteristics (ROC) curve and linear regression model.

Results We evaluated a total of 153 films on 51 patients. The mean ISPDs in neutral position were 16.0, 20.7, 23.2, and 26.0 mm at C5/6, C6/7, C7/T1, and T1/T2, respectively There were no or only weak correlations between ISPD and age, race, height, body weight, and BMI. We observed significant difference between male and female ISPDs at C7/T1 and T1/T2 ($P < 0.05$). The ISPDs had moderate/strong correlations with S-Cobb at each segment ($-0.450 \leq r \leq -0.705$). Based on the ROC curves, the following cutoff values of ISPD provided 100% positive predictive value for segmental lordosis: < 10 mm at C5-6; < 15 mm at each level from C6 to T2.

Conclusion ISPD is a simple and useful parameter that correlates with the segmental Cobb angle. During posterior cervical deformity surgery, surgeons can intraoperatively predict adequate segmental lordosis by utilizing the vertebral level specific cutoff values of ISPD.

Graphical abstract

These slides can be retrieved under Electronic Supplementary Material.



Keywords Inter-spinous process · Distance · Cervical deformity · Posterior · Segmental

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Extended author information available on the last page of the article

Introduction

One of the most challenging issues in performing posterior cervicothoracic instrumented arthrodesis is achieving adequate lordosis, because intraoperative radiography cannot penetrate the shoulder joints [1, 2]. As a result, iatrogenic kyphosis in the lower cervical spine and cervicothoracic junction can occur. Therefore, a simple intraoperative measure to predict segmental lordosis would be valuable.

A wide distance between the spinous processes (interspinous process distance, ISPD) is commonly used as a diagnostic marker for spinal injury or postoperative graft collapse and pseudoarthrosis [3–6]. Unless the vertebra has significant morphological changes, ISPD should be directly related to segmental angles; large ISPD indicates segmental kyphosis, whereas small ISPD indicates segmental lordosis. However, studies describing the relationship between ISPD and segmental kyphotic/lordotic angles, as well as normal ISPD values have been limited.

The purpose of this study is to determine normal ISPD values and its correlation with patients' demographics and, most importantly, to determine a cutoff value that results in segmental lordosis in the posterior cervicothoracic arthrodesis with instrumentation. We hypothesized that ISPD could be used as an indicator of adequate segmental lordosis.

Materials and methods

Patient population and data collection

Following the institutional review board's approval, we retrospectively reviewed the preoperative cervical spine X-rays from patients who undergone cervical spine surgery for degenerative pathologies between January 2016 and December 2017 in a single academic institution. Only the patients with X-rays that showed visible spinous processes in the lower cervical and cervicothoracic segments (C5-T2) on dynamic X-rays (neutral, flexion, and extension) were included in this study. Patients with (1) previous cervical spine surgery, (2) bony fusion in the anterior or posterior column, (3) Klippel Feil syndrome, and (4) significant morphological changes in the vertebral body were excluded from this study. Patients' demographic data, including age, gender, race, height, weight, and body mass index (BMI), were collected. The protocol to obtain the dynamic X-ray was standardized across the whole study cohort; a lateral cervical spine radiograph was taken in the standing position with patients receiving guidance on maintaining a comfortable, straight, horizontal gaze. Then, flexion and extension views were obtained in the patients' maximum effort to flex and extend the cervical spine, respectively. Radiographic analyses included measuring segmental lordotic/kyphotic angles using two different methods: a standard Cobb angle measurement (Cobb 1) and measurement of the angle between the posterior surfaces of the vertebral body (Cobb 2). We defined ISPD as the distance between midpoints of the spinous processes (Fig. 1). The measurement was taken at 150% magnification of standard cervical spine X-ray, which was proven to yield high inter- and intraobserver reliabilities for the ISPDs in the previous report [6]. ISPD values were measured by two independent observers twice at 2-week intervals, and inter- and intraobserver reliabilities were assessed using intraclass correlations (ICCs).

Data analysis

The ISPD values were compared between three positions (neutral, flexion, and extension) according to each segment. Focusing on the lower cervical and upper thoracic spine (C5/6, C6/7, C7/T1, and T1/T2), the specific regions of interest in this study, the correlations between patients' demographic data (age, height, weight, and BMI) and ISPD values were investigated. Gender and race differences in ISPD were also investigated. In addition, the cutoff ISPD values that predict segmental lordosis (Cobb 1 of $<0°$) were determined using the receiver operating characteristics (ROC) curve and linear regression model.

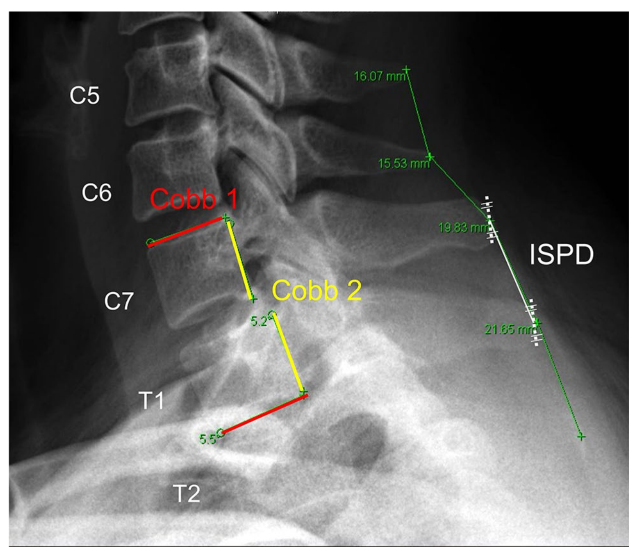

Fig. 1 Radiographic measurements. Segmental lordosis/kyphosis was evaluated by standard Cobb angle (Cobb 1) and angle between posterior surfaces of vertebral body (Cobb 2). Inter-spinous process (ISPD) was defined as the distance between midpoints of edges of the spinous processes

Statistical analysis

Data are presented as the mean ± standard deviation, unless specified otherwise. The inter-observer reliability was calculated according to the ICC and classified as poor (0–0.39), moderate (0.4–0.74), or excellent (0.75–1). Chi-square test and Student's *t* test (paired t test when comparing dynamic X-rays) were used for categorical variables and continuous variables, respectively. Correlations among the radiographic parameters and patients' demographics were analyzed using Pearson's correlation. An ROC curve was created to determine the cutoff ISPD values with the highest (sensitivity − [1 − specificity]). The diagnostic accuracy was evaluated by calculating the area under the curve (AUC). JMP version 13 (SAS, Cary, NC) was used for all analyses. The statistical significance was set at $P < 0.05$.

Results

A total of 153 films on 51 patients' dynamic X-rays were evaluated. Table 1 shows patients' demographics in the study cohort. The ICCs for inter- and intrarater reliabilities on ISPD at each segment were excellent overall, ranging from 0.897 to 0.995 (Table 2).

ISPD values in the current cohort

Table 3 shows the Cobb 1, Cobb 2, and ISPD values in each position. When patients were in a neutral position, the mean ISPD values were 19.8 ± 4.7, 16.8 ± 4.6, 15.2 ± 4.5, 16.0 ± 5.3, 20.7 ± 5.4, 23.2 ± 3.5, and 26.0 ± 5.7 mm at C2/3, C3/4, C4/5, C5/6, C6/7, C7/T1, and T1/T2, respectively. In flexion, patients' ISPDs increased by 4.3 mm (average) at each segment, correlating with increased (kyphotic change) Cobb 1 and 2 angles (all $P < 0.01$). In extension position, ISPDs decreased at C2/3, C3/4, C4/5, C5/6, and C6/7 (all $P < 0.01$), but did not change at C7/T1 ($P = 0.677$) and T1/T2 ($P = 0.410$).

Table 1 Patients' demographics

Total no. of patients	*N* = 51
Age (years)	59.0 ± 16.1
Gender (M/F)	27:24
Race	
White/Caucasian	37
African American	3
Asian	1
Native Hawaiian	1
Unknown	9
Height (cm)	168.1 ± 11.3
Weight (kg)	70.2 ± 15.8
BMI (kg/m^2)	24.1 ± 4.1

BMI body mass index

Table 2 Inter- and intraobserver reliability for ISPD (ICCs [95% confidence interval])

	Inter-observer	Intra-observer
C2/3	0.982 (0.969–0.990)	0.960 (0.931–0.977)
C3/4	0.988 (0.978–0.993)	0.987 (0.977–0.992)
C4/5	0.983 (0.970–0.990)	0.979 (0.964–0.988)
C5/6	0.984 (0.973–0.991)	0.983 (0.970–0.990)
C6/7	0.897 (0.822–0.941)	0.991 (0.984–0.995)
C7/T1	0.993 (0.988–0.996)	0.981 (0.967–0.989)
T1/T2	0.995 (0.991–0.997)	0.990 (0.981–0.995)

Relationship between ISPD and patients' demographics

The primary interest of this study was the alignment in the lower cervical spine and cervicothoracic junction. Therefore, we focused on them in the subsequent analysis. When focusing on the lower cervical spine and cervicothoracic junction (C5/6, C6/7, C7/T1, and T1/T2), ISPD was not significantly correlated with age, race, height, body weight, and BMI ($r < 0.200$ with P values of > 0.05). There was no significant difference between ISPD and gender at C5/6 (16.0 ± 5.6 mm in women vs. 15.9 ± 5.1 mm in men, $P = 0.676$) and C6/7 (19.8 ± 4.9 mm in women vs. 21.5 ± 5.7 mm in men). In contrast, significant gender difference was observed at C7/T1 (21.8 ± 2.4 mm in women vs. 24.4 ± 4.0 mm in men, $P = 0.032$) and T1/T2 (22.7 ± 3.6 mm in women vs. 30.0 ± 5.3 mm in men).

Determination of cutoff ISPD values

The ISPDs had moderate/strong linear correlations with both Cobb 1 and 2 angles at each segment ($-0.450 \leq r \leq -0.705$, $P < 0.01$) (Table 4); the correlation analysis showed similar results between ISPD and Cobb 1 vs. Cobb 2; therefore, we only used Cobb 1 in the subsequent regression analysis. The ROC curves demonstrated acceptable AUC at each segment (range 0.711–0.879) (Fig. 2). Based on these ROC curves, the cutoff ISPD values that determine segmental lordosis (Cobb 1 of < 0°) were 16.7 mm, 24.0 mm, 26.6 mm/26.2 mm, and 28.4 mm/22.1 mm at C5/6, C6/7, C7/T1 (men/women), and T1/T2 (men/women), respectively. The sensitivity, specificity, and positive predictive value (PPV) of each cutoff ISPD values were as follows: C5/6: sensitivity 88.8%, specificity 74.1%, and PPV 76.1%; C6/7: sensitivity 84.2%, specificity 74.5%, and PPV 85.1%; C7/T1 men: sensitivity 72.9%, specificity 67.7%, and PPV 77.7%; C7/T1 women:

Table 3 Segmental Cobb angles and ISPD values in each position

		Neutral	Flexion	*P* (neutral vs flexion)	Extension	*P* (neutral vs extension)
C2/3	Cobb 1 (°)	2.1 ± 4.7	− 1.6 ± 4.7	< 0.01	5.2 ± 4.7	< 0.01
	Cobb 2 (°)	1.8 ± 4.0	− 0.8 ± 4.0	< 0.01	5.2 ± 4.9	< 0.01
	ISPD (mm)	19.8 ± 4.7	22.6 ± 5.1	< 0.01	18.4 ± 4.6	< 0.01
C3/4	Cobb 1	− 0.8 ± 7.0	− 6.6 ± 6.7	< 0.01	5.5 ± 5.4	< 0.01
	Cobb 2	1.0 ± 4.8	− 3.4 ± 4.9	< 0.01	5.3 ± 4.5	< 0.01
	ISPD	16.8 ± 4.6	20.8 ± 4.7	< 0.01	13.7 ± 4.7	< 0.01
C4/5	Cobb 1	− 1.6 ± 7.5	− 8.6 ± 6.7	< 0.01	4.5 ± 7.1	< 0.01
	Cobb 2	0.9 ± 5.3	− 4.5 ± 4.3	< 0.01	5.6 ± 5.4	< 0.01
	ISPD	15.2 ± 4.5	19.5 ± 4.5	< 0.01	11.8 ± 4.1	< 0.01
C5/6	Cobb 1	0.5 ± 6.1	− 5.8 ± 5.8	< 0.01	4.8 ± 6.3	< 0.01
	Cobb 2	1.3 ± 4.5	− 3.7 ± 4.2	< 0.01	4.7 ± 4.9	< 0.01
	ISPD	16.0 ± 5.3	20.2 ± 5.7	< 0.01	13.8 ± 5.1	< 0.01
C6/7	Cobb 1	4.4 ± 6.2	− 2.7 ± 4.5	< 0.01	6.7 ± 6.1	< 0.01
	Cobb 2	4.9 ± 5.7	− 0.9 ± 4.1	< 0.01	7.1 ± 6.2	< 0.01
	ISPD	20.7 ± 5.4	25.3 ± 4.9	< 0.01	19.2 ± 5.5	< 0.01
C7/T1	Cobb 1	2.7 ± 4.6	− 2.3 ± 4.5	< 0.01	2.8 ± 5.0	0.812
	Cobb 2	3.3 ± 4.1	− 0.6 ± 3.7	< 0.01	3.5 ± 4.4	0.739
	ISPD	23.2 ± 3.5	27.8 ± 4.5	< 0.01	23.4 ± 4.5	0.677
T1/T2	Cobb 1	− 0.6 ± 4.2	− 4.1 ± 4.3	< 0.01	− 1.1 ± 3.8	0.285
	Cobb 2	0.8 ± 3.2	− 3.0 ± 3.8	< 0.01	0.2 ± 3.0	0.739
	ISPD	26.0 ± 5.7	29.9 ± 5.4	< 0.01	25.8 ± 5.2	0.410

Paired *t* test was used

ISPD inter-spinous process distance

Table 4 Correlations between ISPD and Cobb 1, Cobb 2

	C5/6		C6/7		C7/T1		T1/T2	
	Correlation coefficient	*P*	Correlation coefficient	*P*	Correlation coefficient	*P*	Correlation coefficient	*P*
Cobb 1	− 0.657	< 0.01	− 0.705	< 0.01	− 0.463	< 0.01	− 0.517	< 0.01
Cobb 2	− 0.661	< 0.01	− 0.697	< 0.01	− 0.450	< 0.01	− 0.522	< 0.01

Pearson's correlation test was used

sensitivity 90.9%, specificity 53.8%, and PPV 74.0%; T1/T2 men: sensitivity 81.8%, specificity 72.0%, and PPV 56.2%; T1/T2 women: sensitivity 57.1%, specificity 96.0%, and PPV 94.1%. The linear regression formulas used to determine the relationship between ISPD and segmental lordosis (Cobb 1) at each segment were as follows: C5/6: Cobb 1 = 13.41–0.81 × ISPD (R^2 = 0.427, $P < 0.01$); C6/7: Cobb 1 = 21.07–0.83 × ISPD (R^2 = 0.497, $P < 0.01$); C7/T1 men: Cobb 1 = 17.12–0.61 × ISPD (R^2 = 0.266, $P < 0.01$); C7/T1 women: Cobb 1 = 12.40–0.47 × ISPD (R^2 = 0.174, $P < 0.01$); T1/T2 men: Cobb 1 = 6.63–0.33 × ISPD (R^2 = 0.139, $P < 0.01$); and T1/T2 women: Cobb 1 = 9.67–0.42 × ISPD (R^2 = 0.282, $P < 0.01$). For ease of use, we determined an ISPD value that would achieve lordosis in 100% of cases (100% PPV: zero false positive). Table 5 lists the ISPD values with estimated Cobb 1 based on the regression formulas (a value predicted based on linear regression models ± root-mean-square error). Accordingly, ISPD of < 10 mm at C5–C6 and < 15 mm at each level from C6 to T2 provided 100% PPV.

Discussion

A commonly seen complication of posterior cervicothoracic arthrodesis is iatrogenic kyphosis or increased C2–C7 sagittal vertical axis [1, 2]. This can result from an inability to visualize the cervicothoracic junction on intraoperative radiographs, which makes it difficult to determine cervical alignment intraoperatively. The purpose of this study was to determine if one could use ISPD, which can be directly

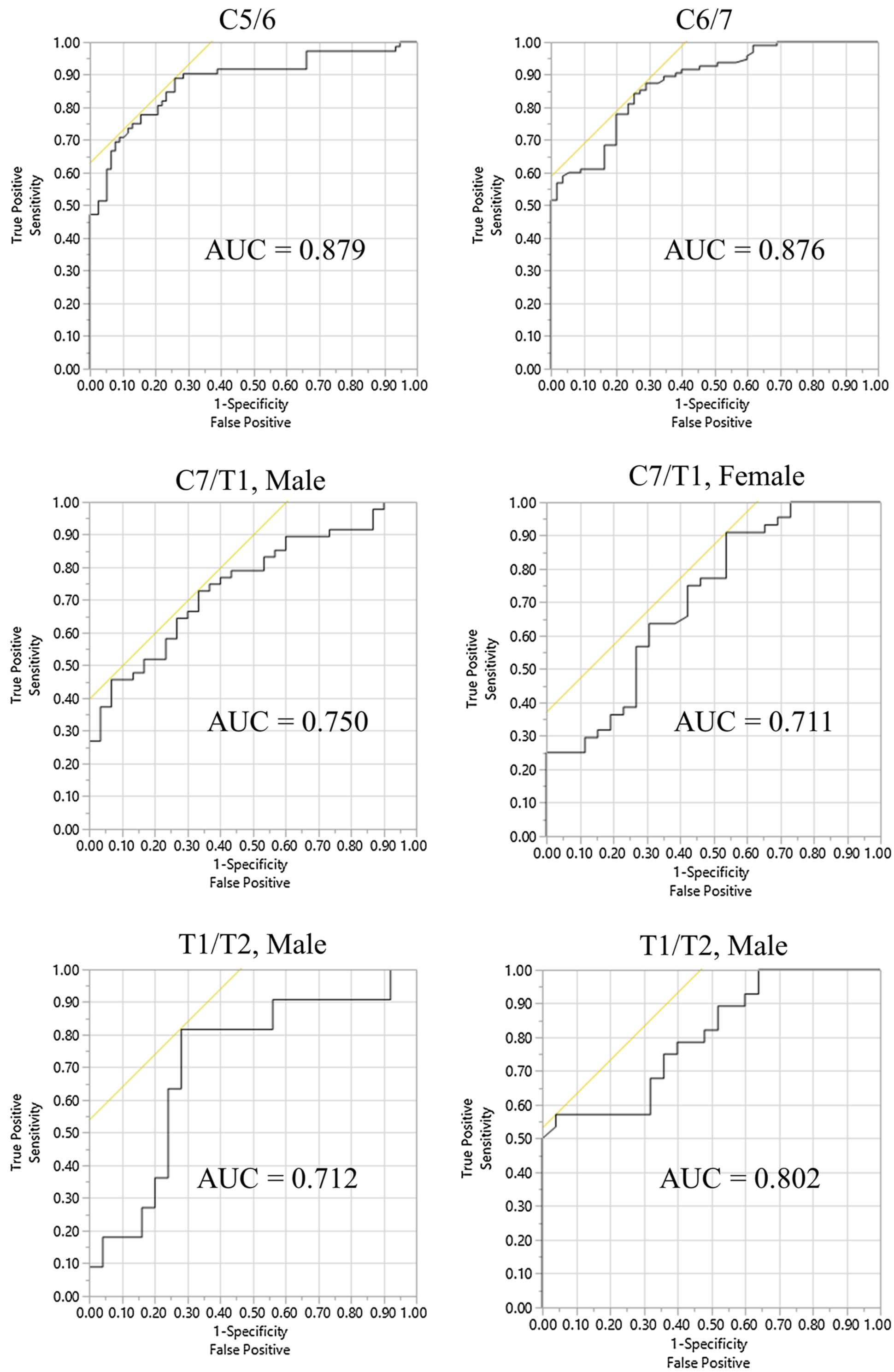

Fig. 2 Receiver operating characteristic (ROC) curves of ISPD as a predictor of segmental lordosis (Cobb 1 < 0°). *AUC* area under the curve

measured by the surgeon, as a proxy for cervicothoracic alignment.

We found that ISPD had moderate/strong linear correlations with both Cobb 1 and 2 angles at each segment ($-0.450 \leq r \leq -0.705$), suggesting that it can be used as a proxy for cervicothoracic alignment. We next determined cutoff ISPD values that would result in segmental lordosis at each level with 100% PPV: < 10 mm at C5–C6; < 15 mm at each level from C6 to T2 (Table 5). We also identified normal ISPD values in the cervical spine, which, to our knowledge, have not been previously studied. Although our study cohort includes patients who underwent cervical spine surgery for degenerative conditions, the majority of the surgical procedures were 1- or 2-level anterior cervical discectomy

Table 5 ISPDs that provide 100% positive predictive value (zero false positive) and estimated segmental lordosis. ISPDs greater than the cutoff values can result in kyphosis

	Gender	Cutoff ISPD	Estimated segmental lordosis
C5/6	–	**10 mm**	**−5.4±5.3°**
C6/7	–	**15 mm**	**−8.6±4.9°**
C7/T1	Male	**15 mm**/20 mm	**−8.0±5.0°**/−5.1±5.0°
	Female	**15 mm**	**−5.3±4.3°**
T1/T2	Male	**15 mm**/20 mm	**−1.7±4.2°**/−0.0±4.2°
	Female	**15 mm**	**−3.3±3.5°**

Estimated segmental lordosis is presented as a value predicted based on linear regression models±root-mean-square error

ISPD inter-spinous process distance

Bold: ISPDs that provide 100% positive predictive value and estimated segmental lordosis

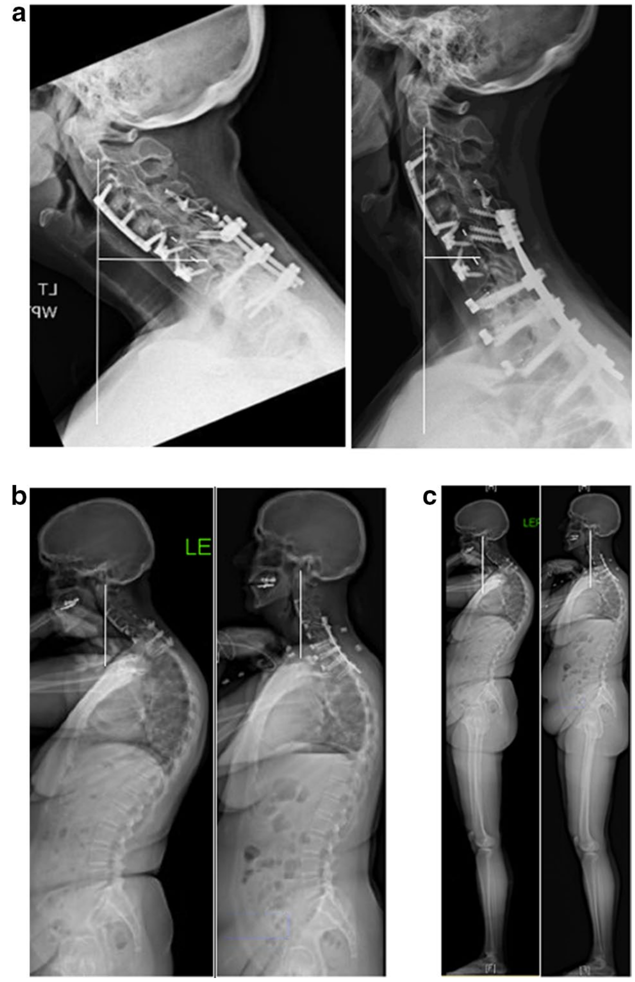

Fig. 3 Revision surgery using the intraoperative ISPD method for inadequate cervical kyphosis after antero-posterior fusion. **a** Cervical lateral radiograph (left: preoperative, right: postoperative), **b** full spine lateral radiograph (left: preoperative, right: postoperative), **c** full body lateral radiograph (left: preoperative, right: postoperative). The preoperative increased C2–C7 sagittal vertical axis (white line) was improved after adequate correction of kyphosis in the cervicothoracic junction

and fusion (ACDF) or arthroplasty. Therefore, there were minimal degenerative morphological changes in the cervical spine. Interestingly, patients' demographics were not significantly correlated with ISPD, indicating that ISPD values are not necessarily affected by patient characteristics, except for gender: Women had lower ISPD values at C7/T1 and T1/T2 than men. The ISPD values in our series were not significantly associated with increased segmental lordosis in extension at C7/T1 and T1/T2; however, kyphotic changes were significant at all segments in flexion. This indicates that sufficient lordosis may not be achieved on extension at the cervicothoracic junction intraoperatively. Therefore, compression force using pedicle screws that allow strong purchase and correction capability might be necessary in these cases [7, 8].

Several studies have described the definition and characteristics of ISPD in the lumbar spine. [9–13] However, studies investigating methods for measuring ISPD in the cervical spine have been limited. Kwon et al., in their study on outcomes of ACDF, defined ISPD as the distance between the most posterior and caudad points of the spinous processes [14]. Similarly, Eubanks et al. [15] determined ISPD by calculating the relative positions of the most posterior and caudal points of the spinous processes. However, these values can be inconsistent with intraoperative ISPD measurements because the most caudal and posterior points of the spinous processes are difficult to determine intraoperatively. Therefore, we defined ISPD as the distance between the midpoints of the tips of each spinous process, which is relatively easy to identify intraoperatively. Spinous processes vary in shape, typically being bifid in the mid-cervical spine [16]. Even with such bifid spinous processes, the midpoint of two bifid spinous processes was easily identifiable, with results showing excellent inter- and intraobserver reliabilities.

Based on the previous literature on asymptomatic populations, the normal segmental lordotic angles are as follows: −1.0° at C5/6, −4.5° at C6/7, −4.0° at C7/T1, and 0° at T1/T2 [17–19]. According to the estimated segmental lordosis predicted from the regression models, the ISPD values that we recommend would achieve these normative values (Table 5). However, surgeons should remember that hyperlordosis can cause iatrogenic foraminal compression and radiculopathy. To prevent such iatrogenic complications, additional foraminotomy may be needed.

Figure 3 demonstrates a typical case scenario of iatrogenic kyphotic deformity due to the malalignment of the cervicothoracic junction. We performed a revision posterior instrumentation without decompression and used the intraoperative ISPD technique to ensure that the kyphosis was adequately corrected. This technique can only be used if the instrumentation is performed before the laminectomy. After the laminectomy, the spinous processes are no longer present or not in continuity with the bone; therefore, the ISPD cannot be measured. If no profound neurological deficit is found, we prefer to perform instrumentation before decompression, as it reduces the risk of iatrogenic cord injury. In such cases, ISPD can be measured. However, in cases of severe cord compression with profound neurological deficits, decompression may be necessary prior to instrumentation.

Some limitations of this study should be noted. First, the degree of segmental lordosis may vary. In addition, the ideal sagittal alignment is likely to vary from patient to patient. Therefore, the segmental angles that result from the cutoff ISPD values presented in our data might result in hyperlordosis in some patients (especially in the elderly). Second, although the radiographically measured ISPD values would represent the actual intraoperative values, the consistency between radiographic and actual intraoperative values remains to be elucidated. Future prospective validation studies using actual intraoperative ISPD values and postoperative measurement of segmental Cobb angles with computed tomography scans are to be conducted, and we are currently collecting data. In addition, there should be a measurement error for ISPD as a small error in ISPD measurement can be exaggerated by the principal of leverage. The present regression analysis showed that a 1-mm error in the ISPD measurement results in 0.3–0.8° prediction error of the segmental Cobb 1 angle. We assume that a 1–2-mm measurement error of the ISPD (resulting in an error of less than 1.6° of the segmental Cobb 1 angle) is acceptable. Finally, we utilized 153 views of 51 patients. Despite being a relatively large sample size, it is possible that there are patients with abnormal morphologies that preclude the use of our data. Therefore, the surgeon must evaluate each patient and use imaging studies to verify that our data are applicable to that individual. Future analysis including data from healthy volunteers is needed.

In conclusion, we have found that ISPD reliably correlates with the sagittal alignment of the cervicothoracic spine. In cases where one cannot assess the alignment using intraoperative radiographs, we recommend using the following ISPDs to ensure lordotic alignment of the cervicothoracic junction: < 10 mm at C5–C6 and < 15 mm at each level from C6 to T2.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval This study was approved by the institutional review board of Columbia University.

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