Observational Study

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Predictors of ultimate postoperative cervical sagittal alignment in main thoracic adolescent idiopathic scoliosis

A long-term follow-up study

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Abstract

This is a retrospective study. The aim of this study was to access sagittal compensatory mechanism of the cervical spine in thoracic adolescent idiopathic scoliosis (T-AIS) before and after posterior spinal fusion and to identify preoperative or immediate postoperative radiographic parameters that can predict the ultimate cervical sagittal alignment (CSA) after long-term follow-up.

A retrospective study was performed on 44 T-AIS patients treated with posterior spinal fusion and with at least 5 years of follow-up. Preoperative, immediate postoperative and latest follow-up radiographs were reviewed measuring cervical lordosis (CL), cervical sagittal vertical axis (CSVA), upper thoracic kyphosis (UTK), main thoracic kyphosis (MTK), global thoracic kyphosis (GTK), lumbar lordosis (LL), pelvic incidence (PI), pelvic tilt (PT), and sacral slope (SS). Pearson correlation analysis, stepwise multilinear regression analysis, and receiver operator characteristic (ROC) curve were performed to define the relationship between ultimate CL and preoperative or immediate postoperative radiographic parameters.

CL significantly improved from 6.6 ± 8.8 degree kyphosis preoperatively to 3.8 ± 8.7 degree kyphosis immediate postoperatively and to 0.5 ± 7.3 degree lordosis at the latest follow-up. Pre- and postoperative CSVA showed no significant difference. Pearson correlation coefficient test showed that CL was only correlated to T1 slope and UTK before surgery, whereas it was correlated to T1 slope, UTK, and GTK after surgery. The following equation was developed to estimate the ultimate CL: ultimate $CL = -2.792 + 0.510 \times \text{Preop CL} + 0.531 \times \text{Postop T1 slope}$. Furthermore, ROC curve showed that preoperative CL ≥ -4.5 degree was strongly predictive and postoperative T1 slope ≥ 11.3 degree was moderately predictive of lordotic cervical spine after long-term follow-up.

For T-AIS patients, CL significantly increased after surgery with the restoration of the global and regional sagittal profile. The sagittal compensatory mechanism of the cervical spine before surgery is different from that after surgery. In these patients, preoperative CL and immediate postoperative T1 slope could be predictors of the ultimate CSA after long-term follow-up.

Abbreviations: CL = cervical lordosis, CSA = cervical sagittal alignment, CSVA = cervical sagittal vertical axis, GTK = global thoracic kyphosis, LL = lumbar lordosis, MTA = main thoracic angle, MTK = main thoracic kyphosis, PI = pelvic incidence, PT = pelvic tilt, PTA = proximal thoracic angle, SS = sacral slope, T-AIS = thoracic adolescent idiopathic scoliosis, UTK = upper thoracic kyphosis.

Keywords: adolescent idiopathic scoliosis, cervical sagittal alignment, long-term follow-up, predictor

1. Introduction

It is well known that sagittal deformity is an important character of adolescent idiopathic scoliosis (AIS) and may play an important role in the pathogenesis of it.[1–5] Previous studies on sagittal deformity in AIS mainly focused on thoracic kyphosis, lumbar lordosis, and pelvic parameters, for example, pelvic incidence (PI) and pelvic tilt (PT).[6–8]

In recent years, the cervical sagittal alignment (CSA) in AIS has received increasing concern. Several studies were conducted attempting to illustrate the pre- or postoperative sagittal compensatory mechanism of the cervical spine in AIS[9–11]; nevertheless, the conclusion remains controversial. Kimura et al[9] reported that 70% of patients with thoracic scoliosis had cervical kyphosis and restoration of cervical lordosis (CL) is correlated to a restoration of thoracic kyphosis. However, Canavese et al[10] found that the strong preoperative correlation between the CL and thoracic kyphosis was lost after scoliosis correction surgery. In a recent study performed by Pesenti et al,[11] postoperative CL was found to be significantly correlated with postoperative T1 slope. Most of these previous studies included patients of all curve types and ignored its potential influence on cervical alignment.[12] Moreover, the previous studies lack long-term follow-up and failed to evaluate the remodeling process of CSA during the follow-up period. Additionally, as the CSA may have an effect on patients' long-term outcome,[13–15] it would be of importance to seek predictive factors of the ultimate CSA, which has not been reported.

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To overcome the aforementioned limitations, we perform this study on main thoracic AIS patients (T-AIS) with a minimum follow-up of 5 years. There were 2 main objectives in the present study. First, we sought to access sagittal compensatory mechanism of the cervical alignment both before and after posterior spinal fusion. Second, we hope to identify preoperative or immediate postoperative radiographic parameters that can predict the ultimate CSA after long-term follow-up.

2. Materials and methods

The institutional review board of the authors' hospital approved this study. Consecutive patients with main T-AIS who were surgically treated between January 2008 and December 2009 were identified based on surgical records. Inclusion criteria for this study were as follows: age <18 at the time of surgery, no revision operations, at least 5 years of follow-up, availability of preoperative, immediate postoperative, and latest follow-up anteroposterior and lateral standing x-rays. Those with poor visualization of radiographs or with their chins up or down were excluded from this study. A total of 44 patients who met all the criteria were included.

All patients were treated with 1-stage posterior correction and fusion surgery using all pedicle screws instrumentation by the same surgical team. Similar instrumentation strategies were used and the fusion levels were determined according to the Lenke et al[16] criteria. The implants used were Legacy rod system (Medtronic Sofamor Danek, Memphis, TN) in all patients.

2.1. Radiological measurements

Standard full-length standing anteroposterior and lateral radiographs were obtained preoperatively, immediate postoperatively, and at latest follow-up. The patients were asked to stand looking straight ahead when they took the full-length standing lateral radiographs. The coronal Cobb angles of proximal thoracic curve (PTA) and main thoracic curve (MTA) were measured. CL (C2-C7) was measured using Cobb method from the lower endplate of C2 to the lower endplate of C7. Lordosis is represented by a positive value and kyphosis is represented by a negative value. Cervical sagittal vertical axis (CSVA) was defined as the horizontal distance from the C2 plumb line to the C7 plumb line. T1 slope was measured from the horizontal to the T1 superior endplate.

Upper thoracic kyphosis (UTK, T1-T5) was measured from the upper endplate of T1 to the lower endplate of T5. Main thoracic kyphosis (MTK, T5-T12) was measured from the upper endplate of T5 to the lower endplate of T12. Global thoracic kyphosis (GTK, T1-T12) was measured from the upper endplate of T1 to the lower endplate of T12.

Lumbar lordosis (LL) was measured from the upper endplate of L1 to the upper endplate of S1. PI was measured from the angle subtended by a line perpendicular to the sacral endplate and another line connecting the center of the femoral head to the midpoint of the sacral endplate. PT was measured from the line connecting the midpoint of the sacral endplate to the axis of the femoral heads and the vertical plane. Sacral slope (SS) was measured from the horizontal to the sacral endplate (Fig. 1).

2.2. Statistical analysis

Statistical analysis was performed using SPSS software (SPSS, Chicago, IL). Student paired *t* test was used to compare pre- and postoperative parameters. Pearson correlation coefficients were applied for correlation coefficient analysis. The correlation coefficient (r) from 0 to 0.1 is considered to represent no association, from 0.1 to 0.3 is considered a weak correlation, from 0.3 to 0.5 is considered a moderate correlation, and from 0.5 to 1 is considered a strong correlation. Statistical analyses were 2-sided, and $P<.05$ with 95% confidence intervals was considered statistically significant. Stepwise multilinear regression analysis was applied to define the relationship between latest follow-up CL and preoperative or immediate postoperative radiographic parameters. Receiver operator characteristic (ROC) curve was done to assess the diagnostic power of the predictors yielded by multilinear regression analysis for predicting ultimate CSA.

3. Results

3.1. Patient demographics

Demographics for the 44 patients included are summarized in Table 1. There were 42 female and 2 male patients in this study (average age 14.1 ± 2.0 years, range 10–18). Thirty of them were classified as Lenke type 1 and the rest were classified as Lenke type 2. The uppermost instrumented level was between T1 and T5 (most common level was T4) and the lowest instrumentation level was at L1 to L3 (most common level was L2). The average duration of follow-up was 6.2 ± 0.9 years (range 5–8).

3.2. Radiographic outcomes

The mean preoperative PTA and MTA were 27.2 ± 6.3 degree and 52.3 ± 11.4 degree, and decreased to 12.7 ± 4.1 degree and 15.5 ± 6.4 degree at the latest follow-up, respectively. CL significantly increased from −6.6 ± 8.8 degree preoperatively to −3.8 ± 8.7 degree immediate postoperatively and to −0.5 ± 7.3 degree at the latest follow-up. Among the 44 patients, 35 (79.5%) had kyphotic CSA and 9 of them (25%) obtained lordotic cervical profile at the latest follow-up. Preoperative lordotic cervical profile in 8 patients all maintained lordotic after surgery. CSVA decreased slightly after surgery but increased during the follow-up period; however, none of these changes were statistically significantly (Table 2, Fig. 2). There were no differences observed between the 2 Lenke types in CL or CSVA preoperatively, immediate postoperatively or at the latest follow-up.

3.3. Correlations between CL and radiographic parameters

Pearson correlation coefficients analysis showed that CL was correlated with T1 slope ($r=0.34$, $P=.022$) and UTK ($r=0.37$, $P=.013$) preoperatively. In immediate postoperative setting, CL was found correlated not only to T1 slope ($r=0.53$, $P=.001$) and UTK (r = 0.34, $P=.025$), but also to GTK ($r=0.37$, $P=.014$). Similar results were also obtained at the latest follow-up with CL strongly or moderately associated with T1 slope ($r=0.68$, $P<.001$), UTK ($r=0.47$, $P=.001$), and GTK ($r=0.47$, $P=.001$). No association was observed between CL and MTK, LL, SS, PT, PI either pre- or postoperatively (Table 3). Additionally, CL was not correlated to the uppermost instrumented level or the lowest instrumentation level neither immediate postoperatively ($P=.386$ and $P=.672$, respectively) nor at the latest follow-up ($P=.268$ and $P=.732$ respectively).

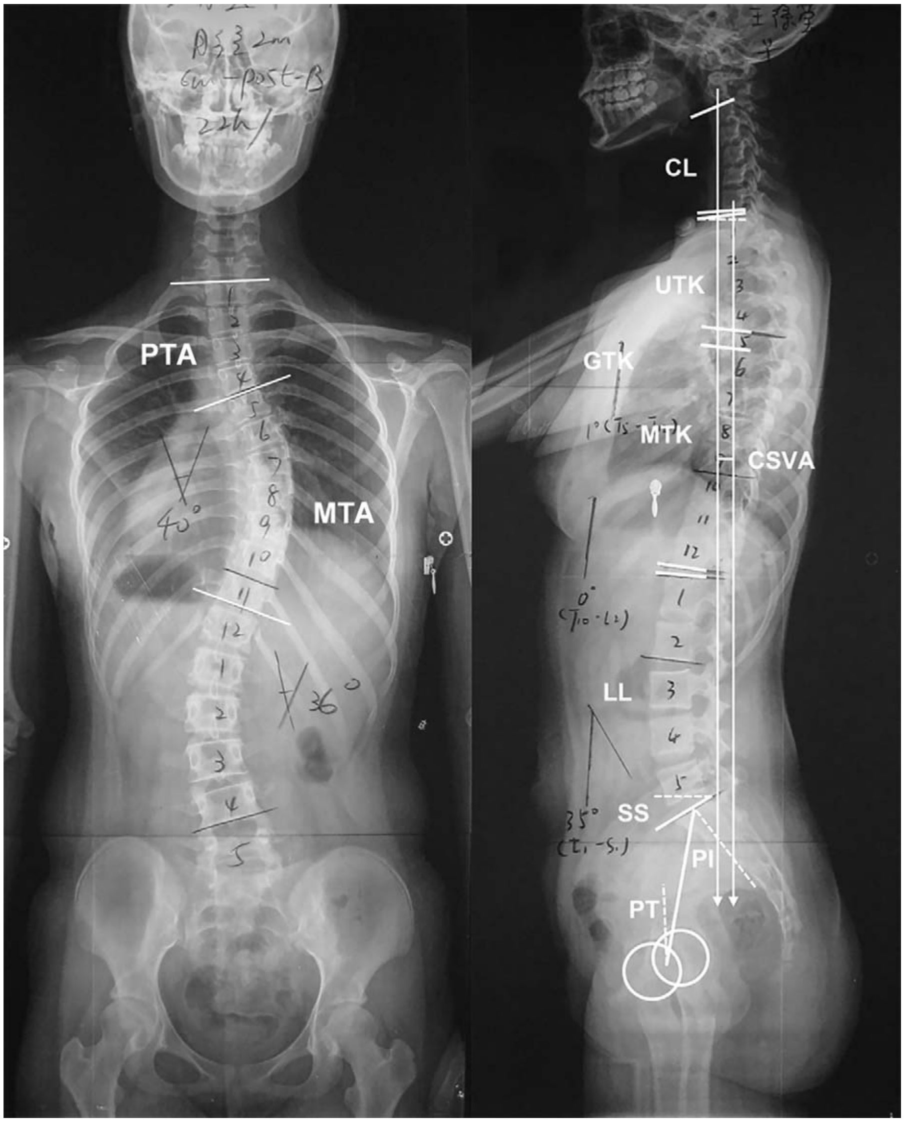

Figure 1. Measurement of coronal and sagittal spine parameters: CL=cervical lordosis, CSVA=cervical sagittal vertical axis, GTK=global thoracic kyphosis, LL=lumbar lordosis, MTA=main thoracic angle, MTK=main thoracic kyphosis, PI=pelvic incidence, PT=pelvic tilt, PTA=proximal thoracic angle, SS=sacral slope, UTK=upper thoracic kyphosis.

3.4. Multilinear regression analysis

Bivariate correlation analysis was used to identify the relationship between the ultimate CL and pre- or postoperative sagittal parameters. All parameters with a $P<.20$ were included in the multilinear regression analysis. Thus, preoperative CL, UTK, MTK, postoperative CL, T1 slope, and GTK were included. Forward stepwise multilinear regression analysis was adopted to avoid multicollinearity. A multilinear regression model revealed that the ultimate CL had a linear correlation ($R=0.802$, adjusted $R^2=0.633$) with the equation composed of preoperative CL, and immediate postoperative T1 slope (Tables 4 and 5) . The equation was shown as follows:

$$\text{Ultimate CL} = -2.792 + 0.510 \times \text{Preop CL} + 0.531 \times \text{Postop T1 slope}$$

Table 1

Patient demographics.

Patients, n	44
Age, y	14.1±2.0 (10–18)
Sex (male: female)	2:42
Risser sign	2.±1.5 (0–5)
Follow-up, y	6.2±0.9 (5–8)
Curve type (Lenke classification)	Type 1 (30); type 2 (14)
Fused vertebrae	12.1±1.3 (9–14)
Upmost instrumented level	T1 (3); T2 (11); T3 (8); T4 (18); T5 (4)
Lowest instrumented level	L1 (13); L2 (18); L3 (13)
Cervical sagittal alignment (patients)	Lordosis (9); kyphosis (35)

3.5. ROC analysis

To further verify the predictive usefulness of the aforementioned predictors—preoperative CL and postoperative T1 slope—an ROC analysis was performed. ROC curve showed that preoperative CL ≥ -4.5 degree was strongly predictive of lordotic cervical spine after long-term follow-up (sensitivity 93.1%, specificity 73.3%, area under curve 0.869, $P<.001$) (Fig. 3).

Table 2

Mean preoperative, immediate postoperative, and latest follow-up values for all radiological variables.

	Preoperative	Immediate postoperative	Latest follow-up	*P*1	*P*2	*P*3
PTA	27.2±6.3	11.8±4.2	12.7±4.1	<.001	.663	<.001
MTA	52.3±11.4	14.1±6.1	15.5±6.4	<.001	.784	<.001
CL	−6.6±8.8	−3.8±8.7	0.5±7.3	.001	.001	<.001
CSVA	11.0±7.0	8.9±7.6	9.8±8.2	.061	.489	.316
T1 slope	9.0±5.4	10.5±3.4	11.9±4.3	.010	.137	.002
UTK	9.6±7.6	10.5±5.7	13.1±5.2	.443	.005	.003
MTK	14.1±8.2	16.8±6.6	16.7±6.3	.036	.932	.046
GTK	23.8±9.2	27.2±7.0	29.1±6.5	.036	.047	.001
LL	46.3±10.4	48.4±11.3	48.3±9.4	.173	.945	.164
SS	36.2±7.3	35.2±8.1	35.0±8.1	.286	.892	.278
PT	5.6±7.0	6.3±8.1	7.2±7.1	.349	.289	.068
PI	41.7±10.6	41.6±11.8	42.4±11.9	.954	.285	.389

*P*1: comparisons of preoperative values and immediate postoperative values; *P*2: comparisons of immediate postoperative values and latest follow-up values; *P*3: comparisons of preoperative values and latest follow-up values. CL=cervical lordosis, CSVA=cervical sagittal vertical axis, GTK=global thoracic kyphosis, LL=lumbar lordosis, MTA=main thoracic angle, MTK=main thoracic kyphosis, PI=pelvic incidence, PT=pelvic tilt, PTA=proximal thoracic angle, SS=sacral slope, UTK=upper thoracic kyphosis.

Additionally, postoperative T1 slope ≥11.3 degree was also moderately predictive of lordotic cervical spine after long-term follow-up (sensitivity 66.7%, specificity 69.0%, area under curve 0.721, $P<.017$) (Fig. 4).

1. Discussion

More and more studies have pointed out that sagittal alignment restoration might be even more important as it can influence the outcome of the surgery.[17–20] CSA has received increasing attention in recent years. Several studies were performed analyzing the sagittal cervical alignment in AIS preoperatively or postoperatively.[9,10,11,21] These studies, however, failed to analyze the differences between the pre- and postoperative sagittal compensatory mechanism of the cervical spine. The present study analyzed both the pre- and postoperative sagittal compensatory mechanism of the cervical spine and further illustrated the remodeling process of cervical spine. Moreover, we sought to identify the pre- and postoperative radiographic parameters, which could determine the ultimate CSA, which may

Figure 2. A 14-year-old female Lenke type 2 patient with spinal fusion showing the progressive improvement in CSA from −24 degree of kyphosis to −1 degree with T1 slope increasing from −2 to 3 degree.

Table 3

Correlations between sagittal parameters and cervical lordosis in preoperative setting, immediate postoperative setting, and at latest follow-up.

		Preoperative							
Preoperative CL		T1 slope	UTK	MTK	GTK	LL	SS	PT	PI
	R	0.37	0.34	0.12	0.19	0.07	0.10	0.296	0.13
	P	.013	.022	.421	.217	.679	.539	.501	.407

		Immediate postoperative							
Immediate Postoperative CL		T1 slope	UTK	MTK	GTK	LL	SS	PT	PI
	R	0.53	0.34	0.24	0.37	0.04	0.06	0.01	0.03
	P	.001	.025	.876	.014	.818	.716	.977	.844

		Latest follow-up							
Ultimate CL		T1 slope	UTK	MTK	GTK	LL	SS	PT	PI
	R	0.68	0.47	0.12	0.47	0.23	0.12	0.228	0.07
	P	<.001	.001	.449	.001	.128	.454	.137	.657

CL = cervical lordosis, GTK = global thoracic kyphosis, LL = lumbar lordosis, MTK = main thoracic kyphosis, PI = pelvic incidence, PT = pelvic tilt, SS = sacral slope, UTK = upper thoracic kyphosis.

Table 4

Correlations between ultimate cervical lordosis and pre- and immediate.

		Preoperative										
Ultimate CL		PTA	MTA	CL	T1 slope	UTK	MTK	GTK	LL	SS	PT	PI
	r	−0.23	−0.11	0.73	0.14	0.22	0.24	0.04	0.03	0.03	−0.28	−0.17
	P	.592	.687	<.001	.368	.151	.125	.805	.871	.856	.63	.280

	Immediate postoperative										
	PTA	MTA	CL	T1 slope	UTK	MTK	GTK	LL	SS	PT	PI
r	−0.16	−0.19	0.70	0.61	0.19	0.41	0.22	0.07	0.04	0.16	0.14
P	.351	.481	<.001	<.001	.220	.792	.155	.648	.803	.292	.381

Postoperative sagittal parameters. CL = cervical lordosis, GTK = global thoracic kyphosis, LL = lumbar lordosis, MTA = main thoracic angle, MTK = main thoracic kyphosis, PI = pelvic incidence, PT = pelvic tilt, PTA = proximal thoracic angle, SS = sacral slope, UTK = upper thoracic kyphosis.

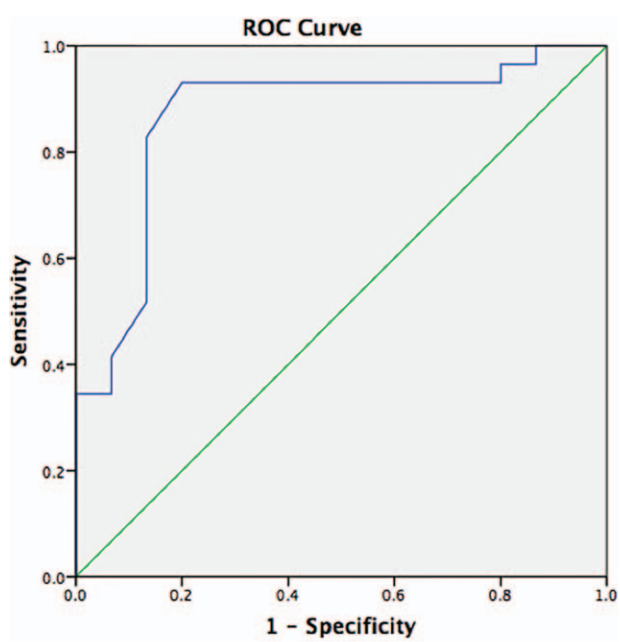

Figure 3. ROC curve for estimated preoperative cervical lordosis. Each point is a cut point for preoperative cervical lordosis at which the sensitivity and specificity for predicting the kyphotic or straightened alignment of the cervical spine at latest follow-up. ROC = receiver operator characteristic.

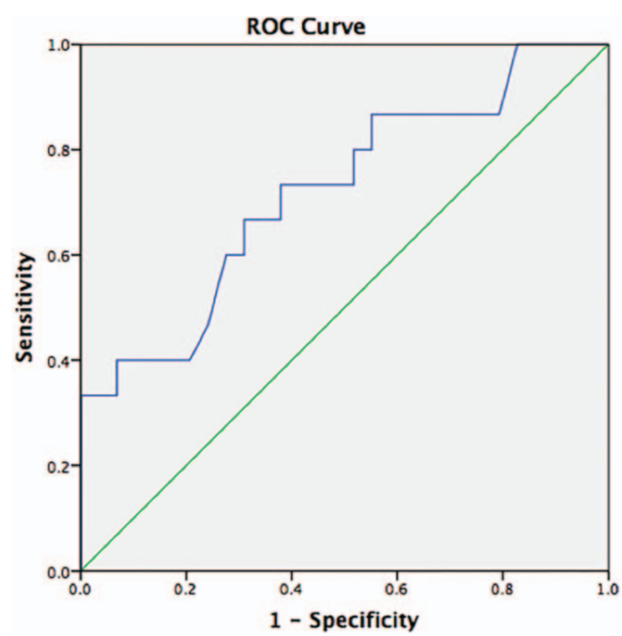

Figure 4. ROC curve for estimated postoperative T1 slope. Each point is a cut point for postoperative T1 slope at which the sensitivity and specificity for predicting the lordotic alignment of the cervical spine at latest follow-up. ROC = receiver operator characteristic.

Table 5

Multiple linear regression model shows correlations between the ultimate CL and immediate postoperative sagittal parameters.

A. Correlation and prediction rates to the multilinear regression model

R	R^2	Adjusted R^2	Std. error of the estimate
0.767	0.588	0.568	4.817

B. Statistically significant intercept and coefficients of the multilinear regression equation for the ultimate CL

	Unstandardized coefficients		Standardized coefficients	t	Sig
Model	B	SE	B	B	SE
(constant)	2.792	3.026		0.922	0.362
Preop CL	0.510	0.096	0.613	5.330	<0.001
Postop T1 slope	0.531	0.246	0.249	2.165	0.036

CL = cervical lordosis, SE = standard error.

help spine surgeons to give proper medical suggestions to AIS patients. Last but not least, to our knowledge, there have been no studies included patients with during 2 years of follow-up. Thus, this study would be the first one focused on both pre- and postoperative sagittal alignment of the cervical spine in AIS with long-term follow-up.

3.6. Preoperative cervical sagittal alignment

Among the 44 patients included in this present study, 35 (79.5%) of them had kyphotic cervical profile, which is consistent with previous studies.[21,22] The Pearson correlation coefficient test showed a significant correlation between CL and UTK, and the correlation between CL and T1 slope was stronger. These results showed that CSA was more likely determined by regional sagittal thoracic alignment, rather than the GTK. The close relationship between preoperative CL and T1 slope has been determined in degenerative cervical spine disorders[23,24]; it was rarely discussed in preoperative AIS patients.[25]

3.7. Postoperative cervical sagittal alignment

Several studies measured the postoperative modification of CSA, coming to different conclusions. Hilibrand et al,[22] for the first time, evaluated the postoperative CL in their AIS patients. They found that scoliosis surgical correction by using Cotrel-Dubousset and Harrington instrumentations failed to achieve satisfactory CSA. However, in this study, the CSA exhibited a significant improvement, with CL increasing from preoperative -6.6 ± 8.8 degree to 0.5 ± 7.3 degree at the latest follow-up. T1 slope and global TK also significantly increased. These results were similar to several previous studies using hybrid constructs.[11,21,26] The inhomogeneity of modification of postoperative cervical spine in different studies may be because of the different implant instruments and uneven change of the global or regional sagittal profile. All our patients underwent posterior surgeries using all pedicle screws, which were believed to offer greater corrective force, and achieved significant improvement of sagittal profile, which may contribute to the restoration of CL.

After the scoliosis correction surgery, a new cervical sagittal compensatory mechanism was established. Postoperative CL was not only correlated with T1 slope and UTK but also correlated with GTK. The change of the relationship between cervical alignment and GTK pre- and postoperatively, which is quite intriguing, shows the influence of the surgery on the sagittal compensatory mechanism of the cervical spine. During the follow-up period, cervical kyphosis continued decreasing from 3.8 ± 8.7 degree to $0.5° \pm 7.3$ degree, with the correlation between CL and T1 slope, UTK, and GTK becoming stronger. These results indicated a remodeling process of cervical sagittal profile after surgery. Correction surgery significantly changed the sagittal alignment of thoracic spine, both globally (GTK) and regionally (T1 slope, UTK), and further induced the alteration of the CSA. Nevertheless, because of the inherent rigidity of the cervical spine, the CSA only partially improved immediately after surgery, and continued improving to adapt to the postoperative spinal sagittal alignment during the follow-up period.

3.8. Predictors of the ultimate CSA

The above-mentioned remodeling process indicated that the ultimate CSA could alter from the immediate postoperative alignment, and finding predictors of the ultimate CSA would be of importance. However, to our knowledge, this topic has not been discussed in any other study.

This study is the first one trying to seek radiographic predictors of the ultimate CSA. By using stepwise multilinear regression analysis, we included all the pre- and postoperative radiographic parameters and successfully identified the preoperative CL, and postoperative T1 slope as the predictors of the ultimate CSA. A predictive equation was also yielded by the regression analysis, which made it possible to predict the precise angle of the ultimate CL. Although the equation was a powerful predictive tool, the complexity of the coefficients in it may restrict its practicability in clinical work.

To provide a more practical way of predicting the ultimate CSA, we utilized ROC curve to identify the cut points for preoperative CL and postoperative T1 slope. According to the ROC curve, preoperative CL ≥ -4.5 degree was strongly predictive and postoperative T1 slope ≥ 11.3 degree was moderately predictive of the ultimate lordotic cervical alignment. As the increase of CL relies on the restoration of regional or global thoracic sagittal profile rather than directly being achieved through surgery, which makes the improvement of CSA limited, patients with a large cervical kyphotic angle (≥ 4.5 degree) are possibly to have a persistent kyphotic cervical alignment. The importance of restoration of T1 slope in achieving satisfactory CSA has been suggested in several previous studies[11,25]; however, it was for the first time quantified in the present study. The cervical alignment in the patients with a satisfied T1 slope restoration (≥ 11.3 degree) may become lordotic in the follow-up period even if it remains kyphotic immediately after surgery.

Abnormal CL has been associated with accelerated disc degeneration and neck pain,[13] and a high incidence of neck pain was reported in patients underwent spinal fusion surgeries after long-term follow-up.[14,15] Achieving ideal CL in scoliosis surgery, therefore, may be important to prevent secondary cervical spine pathologies. For those patients who are predicted to have kyphotic cervical alignment according to the aforementioned predictors, close observation and proper cervical spine exercise guidance are required.

Limitations of the present study lie in its retrospective design, relatively small number of patients, and the potential influence of head motion on the standing lateral radiographs. Strict inclusion and exclusion criteria and comparatively high rate of loss of follow-up may be responsible for the small number of patients. In this study, all patients were required to look straight forward when they took the full-length standing lateral radiographs and those with their chins up or down were excluded, which may minimize the effect of head motion.

4. Conclusions

T-AIS patients frequently have hypolordotic or kyphotic cervical spines. For those patients, CL partially improved immediately after surgery and continued improving during the follow-up period. The sagittal compensatory mechanism of the cervical spine before surgery was different from that after surgery. CSA was only determined by regional sagittal profile of the thoracic spine (T1 slope and UTK) before surgery, whereas it was strongly or moderately correlated with both regional and global sagittal thoracic profile including T1 slope, UTK, and GTK after surgery. Preoperative CL and immediate postoperative T1 slope could be predictors of ultimate CL after long-term follow-up. Patients with preoperative CL ≥ -4.5 degree and postoperative T1 slope ≥ 11.3 degree are likely to have lordotic cervical alignment after years of follow-up.

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