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The Change of Matching Between T1 Slope and Cervical Lordosis after Anterior and Posterior Reconstruction Surgeries for Patients with Multilevel Cervical Spondylotic Myelopathy: A Retrospective Study

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Keywords:

Cervical spondylotic myelopathy; T1 slope; Cervical lordosis; Reconstruction surgery

1. Abstract

1.1. Objective

To compare the changes in the matching degree between T1 slope (T1S) and cervical lordosis (CL) in patients with multilevel cervical spondylotic myelopathy (CSM) after anterior and posterior reconstruction surgeries.

1.2. Methods

In accordance with STROCSS criteria, the study enrolled 134 patients with multilevel CSM and T1S-CLvalue<20° from the medical records spanning 2015 to 2020. The anterior group underwent anterior cervical discectomy and fusion or discectomy combined corpectomy hybrid decompression and reconstruction technique. The posterior group received laminoplasty or laminectomy with fusion. This study retrospectively analyzed perioperative parameters: operated level, operation times, bleeding amounts and hospital stays; clinical parameters: JOA score, VAS and NDI; and radiologic parameters: T1S, CL, C2-7 SVA.

1.3. Results

Prior to surgery, there were no significant differences in preoperative factors. Postoperatively, the anterior group showed significantly lower values in NDI, VAS scores, perioperative parameters and incidence of complications. Significant changes were observed in each group for T1S, CL, C2-7 SVA and T1S-CL. Preoperatively, in the anterior group, significant correlations were identified between T1S-CL and T1S, T1S-CL and CL, and T1S-CL and C2-7 SVA. In the posterior group, correlations were observed between T1S-CL and T1S, T1S-CL and CL, and T1S-CL and C2-7 SVA. The comparative analysis of parameter changes revealed significant differences in the change of C2-7 lordosis and T1S-CL.

1.4. Conclusion

Anterior reconstruction surgery can optimize the matching degree of T1S-CL, while mismatch of T1S-CL is more likely to occur after posterior reconstruction surgery, potentially leading to cervical sagittal malalignment and imbalance in patients with multilevel CSM.

2. Introduction

Cervical spondylotic myelopathy (CSM) is an age-related and degenerative disease with spinal cord dysfunction, which significantly diminishes the quality of life [1, 2]. At present, the prevailing strategy for is operative decompression [3, 4]. It has been well acknowledged that reconstruction approaches encompass both anterior and posterior paths [2-4]. Although the benefits and drawbacks of these methods have been widely reported by various studies previously, the optimal technique for CSM decompression and reconstruction remains controversial [5-8].

The alignment and balance of the cervical spine in the sagittal plane are crucial for the recovery of neural function. Consequently, cervical sagittal parameters are of paramount importance and must be carefully considered during reconstructive procedures [9-11]. The correlation between the T1 slope (T1S) and the cervical lordosis (CL) mirrors the relationship between pelvic incidence (PI) and lumbar lordosis (LL), such that a larger T1S necessitates a proportionally greater CL to maintain head balance, akin to how a larger PI demands a greater LL for optimal spinal alignment. Previous studies have suggested that the match of T1S and CL, along with other cervical sagittal parameters, may serve as indicators of postoperative functional capabilities. A mismatch, defined by T1S-CL > 20°, may signal a risk of postoperative deterioration following posterior reconstruction in patients with multilevel CSM [12,13]. However, how T1S-CL matching changes after anterior reconstruction still remains to be determined. The present study aims to determine the changes of T1S-CL in patients with initially normal match of T1S-CL who underwent either anterior or posterior reconstruction.

3. Materials and Methods

3.1. Participants

Written informed consent was acquired from each patient prior to the study. Multisegment cervical spondylotic myelopathy (MCSM) patients with a normal match [14] of T1S-CL (T1S-CL value<20°) who underwent anterior reconstruction, including anterior cervical discectomy and fusion (ACDF) and hybrid decompression and reconstruction technique of anterior cervical corpectomy and fusion (ACCF), and posterior reconstruction including laminoplasty (LAMP) and laminectomy with fusion (LF) in the department of spine surgery from January 2015 to December 2020 were recruited. The inclusion criteria for the study were as follows: (I) adult patients with a diagnosis of degenerative CSM and preoperative multilevel impairment confirmed by MRI; (II) patients who underwent either ACDF or hybrid decompression and reconstruction technique for anterior reconstruction, and either laminoplasty or laminectomy with fusion for posterior reconstruction; (III) patients with a follow-up period longer than 24 months and presented integrate clinical data. The exclusion criteria were: (I) patients who underwent other spine surgeries before the surgeries performed in the hospital; (II) patients with T1 vertebral body blocked by sternum or ribs on lateral X-ray radiographs taken in a neutral standing position with a horizontal gaze; (III) patients with a history of osteoporosis, trauma, tumor, or infection affecting the cervical spine.

3.2. Surgical Technique

All surgeries were performed by the same senior surgeon, and patients were required to wear soft collars for six weeks postoperatively.

3.2. Anterior Reconstruction

The anterior approach involved a hybrid decompression and reconstruction technique, including ACDF and corpectomy. ACDF was performed under general anesthesia with the standardized right-sided Robinson-Smith anterior approach. The patient was positioned supine, with a gelfilled roll placed transversely beneath the scapulae to achieve slight cervical hyperextension. Lateral fluoroscopy was performed to confirm the correct vertebral level. A right-sided incision was made at the appropriate cervical level, followed by division of the platysma and blunt dissection down to the deep prevertebral fascia. Following a second fluoroscopy, the hyperplastic osteophyte, degenerative disc and posterior longitudinal ligament were removed. The cages filled with bone fragments were inserted into the intervertebral space. The vertebral body of the decompression area was fixed by the titanium plate. Corpectomy was meticulously performed using a high-speed bur to preserve the integrity of nervous and vascular systems and adjacent soft tissues. Uncinate processes were identified and used as reference points to determine the width of the corpectomy. The posterior longitudinal ligament was removed with a Kerrison rongeur, exposing the dura mater. The decompressed segment was measured to fit a Tantalum trabecular metal (TTM) implant, designed to match the anatomy of the adjacent end plates.

3.3. Posterior Reconstruction Technique

LAMP was performed under general anesthesia with patients positioned prone and their heads fixed using the Mayfield head holder. Lateral fluoroscopy was applied to determine the level for operation. The lamina and spinous processes were exposed by a posterior midline approach, and the side with relatively severe clinical symptoms and/or radiographic compression was selected as the open side. Both the outer and inner cortical margins were drilled with a high-speed drill, while preserving the inner cortical margin of the hinge side. The lamina was then lifted from the open side towards the hinge side and fixed in an expanded position using 8-12 mm miniplates. Laminotomy and fusion (LF) was also performed under general anesthesia with patients in a prone position. A similar posterior midline approach as in laminoplasty was used to expose the spinous processes, laminae, facet joints, and transverse processes. Subsequently, the lateral mass screws and prebent titanium rods were placed at the target segment, followed by resection of the lamina and ligamentum flavum. Autologous bone grafts from the lamina were placed adjacent to the bilateral joints to facilitate fusion.

3.4. Clinical and Radiographic Evaluation

Data collection occurred prior to surgery and at the conclusion of the final follow-up period. The Japanese Orthopedic Association (JOA) scores, Neck Disability Index (NDI) and the visual analog scale (VAS) scoring system evaluating neurological outcomes were used for clinical assessment. Complications including dysphagia, hematoma, axial pain, cerebrospinal fluid leakage, C5 paralysis, infection, or deterioration in neurologic deficits were recorded, and rates of each complication were calculated and compared among different groups. The cervical sagittal parameters were measured on the lateral X-ray radiographs as illustrated in Figure 1 before surgery and at the final follow-up. T1 slope was determined by measuring the angle between the horizontal plane and the T1 upper endplate; and cervical lordosis was determined by measuring the angle between the C2 and C7 lower endplates, with an alignment of CL<0°defined as kyphosis. C2-7 SVA was determined by measuring the distance between the C2 plumb line and the posterior superior endplate of C7, with an alignment of C2-7 SVA >40 mm defined as sagittal imbalance. T1S-CL was calculated as T1 slope minus cervical lordosis, with a value of T1S-CL<20°defined as normal match. Mismatch was defined as T1S-CL>20°.

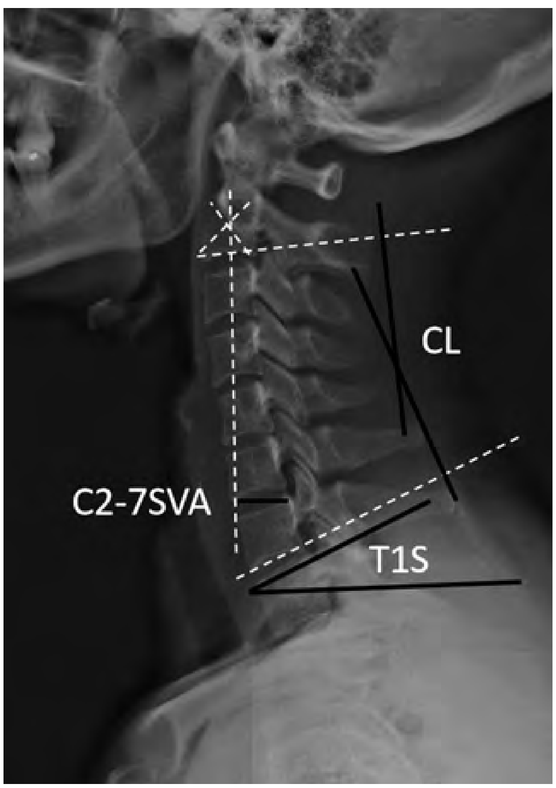

Figure 1: Measurements of parameters, including T1 slope, cervical lordosis, and C2-7 SVA on lateral X-ray radiographs.

3.5. Statistical Analysis

Statistical analysis was performed using SPSS version 26.0 (IBM, Armonk, New York, USA, version 11), with P value < 0.05 considered statistically significant. Continuous variables were calculated as mean value±standard deviations (SD), and categorical variables were calculated as frequencies. Chi-square analysis was performed to compare categorical variables among groups. Non-parametric analysis, independent and paired t test was used to compare the continuous variables in and between the two groups. The Pearson correlation coefficient was used to analyze correlations between each radiological parameter.

6. Results

6.1. Demographics

The baseline characteristics of the patient cohort were summarized in Table 1. The anterior group comprised 69 patients (37 males and 32 females) with an average age of 59.1±11.8 years (36 - 75 years). The posterior group consisted of 65 patients (39 males and 26 females) with an average age of 56.2±11.9 years (37 - 78 years). All patients were followed up with average period of 28.6±2.9 months (24 - 39 months). There were no statistically significant differences between the groups in terms of average age, sex ratio, anatomical level for operation and follow-up periods (P>0.05). Notably, the anterior group experienced a shorter operative time (126.6±7.9 vs 148.2±15.5 min, P<0.001), less blood loss (153.6±59.6 vs 293.1±72.8 ml, P<0.001) and shorter hospital stay (9.4±1.8 vs 11.5±1.4 day, P<0.001) comparing with posterior group.

6.2. Comparison of Clinical Measurements

The clinical outcomes, as summarized in Table 2 and Table 3, revealed that prior to surgery, there were no significant differences in the T1S, C2-7 CL, C2-7 SVA, T1S-CL, JOA score, VAS-neck score and NDI between the groups (P>0.05). At the final follow-up, all parameters were improved significantly in each group (P<0.001). The NDI and VAS-neck score were significantly higher in the posterior group (P=0.004 and P=0.002, respectively), while the JOA score showed no significant differences between groups (P>0.05).

Table 1: Demographic data of the patients in two groups (mean ± SD).

Characteristic	Anterior group	Posterior group	t	*P*
Surgery, n	ACDF: 51	LAMP: 9	-	-
	Hybrid: 18	LF:56		
Sex (male/female), n	37/32	39/26	0.449	0.503
Age (years)	59.1±11.8	56.2±11.9	1.279	0.203
Operated level	C3-C6: 33	C3-C6: 37	1.11	0.292
	C4-C7: 36	C4-C7: 28		
Operation-time (min)	126.6±7.9	148.2±15.5	-10.044	0
Blood loss (ml)	153.6±59.6	293.1±72.8	-12.089	0
Hospital stay (days)	9.4±1.8	11.5±1.4	-7.339	0
Follow-up (months)	28.4±2.7	28.7±3.2	-0.625	0.531

Table 2: Clinical and radiographic outcomes in two groups (mean ± SD).

Parameters	Anterior group				Posterior group			
	Pre-op	Post-op	t	*P*	Pre-op	Post-op	t	*P*
T1S (°)	24.7±6.7	32.8±7.8	-15.017	0.000	24.1±7.6	32.1±7.1	-14.799	0.000
C2-7 CL (°)	14.1±8.0	19.6±8.3	-13.239	0.000	13.5±8.7	9.9±8.1#	6.072	0.000
C2-7 SVA (mm)	15.6±8.2	20.6±8.1	-40.145	0.000	16.4±8.7	21.4±8.6	-38.708	0.000
T1S-CL (°)	9.5±4.1	12.1±4.4	-9.065	0.000	9.8±4.1	22.3±2.4#	-33.518	0.000
JOA	10.1±1.7	15.1±1.3	-20.118	0.000	9.9±2.3	14.9±1.3	-14.724	0.000
NDI	46.6±6.4	26.5±7.1	16.656	0.000	47.4±7.1	29.9±6.2#	16.509	0.000
VAS	2.1±1.5	0.8±0.6	6.311	0.000	2.3±1.1	1.3±1.0#	5.701	0.000

Note: pre-op, preoperation; post-op, postoperation;#, compared with anterior group, $P<0.05$.

Table 3: Correlations among preoperative radiologic parameters before and after surgery.

	Parameters	T1S (°)	C2-7 CL (°)	C2-7 SVA (mm)
Before surgery	C2-7 CL (°)	r1=0.351, *P*1=0.003 r2=0.369, *P*2=0.003		
	C2-7 SVA (mm)	r1=-0.247, *P*1=0.041 r2=-0.251, *P*2=0.043	r1=-0.406, *P*1=0.001 r2=-0.429, *P*2=0.000	
	T1S-CL (°)	r1=0.282, *P*1=0.019 r2=0.260, *P*2=0.037	r1=-0.250, *P*1=0.038 r2=-0.311, *P*2=0.012	r1=0.240, *P*1=0.047 r2=0.362, *P*2=0.003
After surgery	C2-7 CL (°)	r1=0.240, *P*1=0.047 r2=0.366, *P*2=0.003		
	C2-7 SVA (mm)	r1=-0.275, *P*1=0.022 r2=-0.258, *P*2=0.038	r1=-0.389, *P* 1=0.001 r2=-0.250, *P* 2=0.045	
	T1S-CL (°)	r1=0.256, *P*1=0.034 r2=0.171, *P*2=0.172	r1=-0.323, *P* 1=0.007 r2=-0.210, *P* 2=0.094	r1=0.312, *P*1=0.009 r2=0.438, *P*2=0.000

Note: 1, anterior group; 2, posterior group.

6.3. Comparison of Radiographic Measurements

The radiographic outcomes, as detailed in Table 2 and Table 3, indicated that prior to surgery, there were no significant differences between the groups in terms of T1S, C2-7 lordosis, C2-7 SVA and T1S-CL. However, post-surgery, a significant difference was noted in the CL, which was substantially higher in the anterior group compared to the posterior group (19.6±8.3 vs 9.9±8.1, P<0.001). Conversely, the T1S-CL value was significantly lower in the anterior group (12.1±4.4 vs 22.3±2.4, P<0.001). The T1S and C2-7 SVA showed no statistically significant difference between groups following surgery (P>0.05). Furthermore, the change of each radiologic parameter was defined and calculated according the formula of postoperative value minus preoperative value. Comparison of the alterations in radiological parameters between the two groups is presented in Table 4. The change in T1 slope (ΔT1S) and C2-7 SVA (ΔC2-7 SVA) between the anterior and posterior groups was not statistically significant (P>0.05). However, the changes in C2-7 lordosis (ΔC2-7 lordosis) and T1S-CL (ΔT1S-CL) were significantly higher in the anterior group compared with posterior group (P<0.001).

Table 4: Comparison of the alterations in radiological parameters between the 2 groups.

Parameters	Anterior group	Posterior group	t	*P*
ΔT1S (°)	8.2±3.9	7.9±4.1	-0.376	0.707
ΔC2-7 CL (°)	5.3±1.8	-3.5±3.3	-18.762	0.000
ΔC2-7 SVA (mm)	5.2±2.3	5.0±2.4	-0.475	0.636
ΔT1S-CL (°)	4.0±2.2	11.0±2.8	15.740	0.000

6.4. Analysis of Complications

All cases presented wound healing at grade IA before discharge. A comparison and summary of postoperative complications are presented in Table 5. The incidence of axial pain was significantly lower in the anterior group compared to the posterior group (0/69 vs 4/61, P=0.036). Additionally, the overall incidence of complications was lower in anterior group (2/67 vs 8/57, P=0.034).

Among the specific cases, one patient who underwent a 4-level ACDF had C5 palsy (Figure 2), and one patient who underwent hybrid surgery (two discs discectomy combined one vertebra corpectomy) suffered from dysphagia (Figure 3). There were three patients with two complications each, including two patients who underwent LF experienced cerebrospinal fluid leakage (CFL) and axial pain (Figure 4), and one patient with fat liquefaction and asymptomatic epidural hematoma. Furthermore, five patients who underwent LAMP each had one complication, including three cases with axial pain, one case with CFL, and one case with fat liquefaction (Figure 5). No patients suffered infection, deterioration in neurologic deficits, graft dislodgement or subsidence complications. The case with C5 palsy rehabilitated after hyperbaric oxygenation, and the case with dysphagia faded 6 months after surgery.

Table 5: Postoperative complications in two groups.

Complications	Anterior group (Yes/No)	Posterior group (Yes/No)	χ^2	*P*
dysphagia	1/68	0/65	0.949	0.330
epidural hematoma	0/69	1/64	1.070	0.301
C5 palsy	1/68	0/65	0.949	0.330
SFL	0/69	3/62	3.258	0.071
axial pain	0/69	4/61	4.377	0.036
fat liquefaction	0/69	2/63	2.155	0.142
infection	0/69	0/65	-	-
neurologic deficit	0/69	0/65	-	-
graft dislodgement	0/69	0/65	-	-
subsidence	0/69	0/65	-	-
Total	2/67	8/57	4.487	0.034

Figure 2: Change of T1S-CL after 4-level ACDF: A 61-year-old male patient with preoperative T1S-CL matching. (2A-2B) Before surgery, T1S was 23.5°, CL was 15.2°, C2-7SVA was 14.6 mm and T1S-CL was 8.3°. (2C-2D) At the 24-month follow-up, T1S was 32.6°, CL was 20.5°, C2-7SVA was 19.9 mm and T1S-CL was 12.1°. Cervical alignment and lordosis were well reconstructed and maintained.

Figure 3: Change of T1S-CL after 4-level discectomy combined corpectomy surgery: A 56-year-old female patient with preoperative T1S-CL matching. (3A-3B) Before surgery, T1S was 22.6°, CL was 15.3°, C2-7SVA was 15.1 mm and T1S-CL was 7.3°. (3C-3D) At the 28-month follow-up, T1S was 33.7°, CL was 21.5°, C2-7SVA was 20.3 mm and T1S-CL was 12.2°. Cervical alignment and lordosis were well reconstructed and maintained.

Figure 4: Change of T1S-CL after C3-C7 laminoplasty surgery: A 46-year-old male patient with preoperative T1S-CL matching. (4A-4B) Before surgery, T1S was 21.7°, CL was 14.5°, C2-7SVA was 13.9 mm and T1S-CL was 7.2°. (4C-4D) At the 25-month follow-up, T1S was 34.8°, CL was 8.9°, C2-7SVA was 21.1 mm and T1S-CL was 25.9°. Cervical sagittal alignment was at a state of hyperextension forward.

Figure 5: Change of T1S-CL after C3-C6 laminectomy with fusion: A 49-year-old male patient with preoperative T1S-CL matching. (5A-5B) Before surgery, T1S was 20.9°, CL was 14.3°, C2-7SVA was 15.1 mm and T1S-CL was 6.6°. (5C-5D) At the 30-month follow-up, T1S was 31.8°, CL was 9.7°, C2-7SVA was 9.3 mm and T1S-CL was 22.1°. Cervical sagittal alignment was straightened.

7. Discussion

CSM is typically characterized by gradual degeneration of the cervical spine and compression of the spinal cord, resulting in neurologic disability and affecting quality of life [3,15]. The severity of these manifestations is often exacerbated in patients with multilevel CSM. Physiologically, the condition can lead to alterations in the cervical spine's sagittal alignment and balance. Correspondingly, radiographic assessments reveal subsequent changes in the relationships between cervical sagittal parameters [11,16]. The cumulative effect of these changes in radiological parameters and their matching relationships can lead to cervical symptomatology and sagittal imbalance of the cervical spine. Hence, when conservative treatments prove ineffective for multilevel CSM, surgical intervention becomes the routine course of action [15,17]. The advantages and disadvantages of various decompression and reconstruction strategies have been widely discussed by previous studies [18-21]. As conventional and effective techniques, the anterior approaches of ACDF and hybrid technique are preferred for minimization of muscle damage, direct decompression, optimal stability and effects for cervical lordosis reconstruction [22,23]. While the therapeutic effectiveness of decompression is comparable between anterior and posterior approaches, the latter, including LAMF and LF, are not favored due to their limited capacity for rebuilding cervical sagittal alignment [24,25]. In addition, a higher incidence of postoperative complications, such as loss of function and secondary problems, raise significant consideration when making surgical strategies [26]. Given these factors, , the anterior decompression and reconstruction is favored over the posterior approach.

Radiological parameters are known to undergo changes subsequent to reconstructive surgeries, with unique correlations emerging among these modifications [27,28]. T1S-CL was used to evaluate cervical sagittal matching in this study [12,13]. As known, T1 slope is positively correlated with cervical lordosis, while C2-7 SVA is negatively correlated with both T1 slope and cervical lordosis in asymptomatic adults. Previous studies has documented significant shifts in these parameters following both anterior and posterior reconstructive surgeries. However, few attention has been paid to the change of correlations between cervical imaging parameters [27,28]. In the present study, T1 slope and C2-7 SVA increased significantly after reconstructive surgeries, irrespective of the approach. In contrast, the CL exhibited a divergent response, with an increase noted in the anterior group and a decrease in the posterior group. Notably, the relationships among these parameters altered in both groups, albeit in a non-uniform manner. Interestingly, T1S-CL was not correlated with either T1S or CL. Conversely, a positive correlation was identified between T1S-CL and C2-7 SVA, indicating that mismatch of T1S-CL is associated with cervical sagittal balance. One plausible explanation for this association is that the damage of posterior muscle-ligament complex resulted in cervical sagittal mismatch and imbalance. Therefore, T1S-CL<20°is an ideal prerequisite condition for objectively assessing cervical sagittal balance and ensuring a physiologically normal functional state.

Perspectives based on radiological data confirmation have guiding effects on our clinical work. Although, a variety of treatment options, such as anterior decompression fusion and posterior laminectomy or laminoplasty combined fusion, could prevent the progressive deterioration of neurologic function, a consensus on the most appropriate surgery management has yet to be established. The precise localization and ossification status of spinal cord lesions are critical determinants that inform surgical strategy. Nonetheless, the significance of radiological parameters is paramount and cannot be overlooked. Studies have demonstrated that the match between T1S and CL were associated with neck disability and cervical sagittal balance after posterior cervical reconstruction [29].

Cervical sagittal imbalance, both clinically defined and radiographically indentified, are often associated with functional disability and neck pain after invasive intervention [13,30]. This study's analysis compared imaging parameters and revealed improvements in these parameters and their correlations after reconstructive surgery. The alterations in radiological parameters post-surgery, along with changes in matching of cervical sagittal parameters, are indicative of the complex interplay between surgical outcomes and spinal balance. Statistically significant differences in postoperative NDI and VAS scores between groups highlight the potential impact of T1S-CL mismatch. This mismatch may stem from the weakness of the posterior neck structure and poor anterior reconstruction. In the posterior surgery group of this study, an increase in T1S and a decrease in CL were observed, contributing to a state of decompensation in the suboccipital and neck muscle groups. This suggests the activation of compensatory mechanisms in the cervical spine and cervicothoracic alignment aimed at maintaining or regulating cervical sagittal balance. Consequently, the observed high incidence of axial pain and neck disability in the posterior group is not surprising, given the critical role of these anatomical and physiological factors in post-surgical recovery and function.

The present study has several limitations. Firstly, it was a retrospective and single-centered study, which may influence the generalizability of its findings. Secondly, while the T1S-CL was utilized to reflect the relationship between the cervical spine and the cervicothoracic junction, a comprehensive assessment of the cervicothoracic junction and thoracic spine radiographic parameters was not undertaken. Thirdly, the change in the whole spine alignment and compensatory mechanism cannot be ignored after local spine surgery. These factors are known to play a significant role in postoperative outcomes and patient recovery. Therefore, further prospective, randomized controlled and multicentered clinical trials should be conducted to confirm these findings. Such studies would offer a more robust validation of the results and contribute to a broader understanding of spinal pathophysiology and treatment efficacy.

8. Conclusions

T1S-CL is an independent and instructive radiographic parameter for surgical decision-making. Our findings indicate that anterior reconstruction surgery significantly improves T1S-CL matching, while posterior approaches may lead to mismatch, potentially causing cervical malalignment and imbalance. The T1S-CL parameter is thus essential for optimizing surgical strategies and patient outcomes in CSM.

9. Author Contributions

Study conception and design were done by TL, QSQ and HZM. Acquisition of data was done by ZZZ and JK. Analysis and interpretation of data were performed by TL. All authors made substantial contributions to revising this manuscript for intellectual content and approved the final published version. QSQ and HZM had full access to all data in the study and took responsibility for ensuring the integrity of data and the accuracy of data analysis. All authors contributed to the article and approved the submitted version.

10. Ethical Approval

The retrospective study was approved by the Ethics Committee of the Shanghai Fourth People's Hospital Affiliated to Tongji University School of Medicine (Ethics number: 2021-107-001).

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