T1 slope minus cervical lordosis in multilevel anterior cervical discectomy and fusion with or without plate: a mean 6-year follow up

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Research article

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Abstract

Purpose

Cervical alignment between self-locked cage (SLC) and anterior cage-with-plate (ACP) system was debatable, especially in multilevel anterior cervical discectomy and fusion (ACDF). T1 slope minus C2-C7 cervical lordosis (T1S-CL) was critical for cervical-balance while without identified threshold. Thus the study was to compare sagittal alignment between SLC and ACP on 3-level ACDF and to identify the threshold of T1S-CL in 3-level ACDF.

Methods

45 patients of 3-level SLC and 28 cases of 3-level ACP with well-matched demographics were retrospectively enrolled with 6.1-year follow-up. Cervical alignment paramters were CL, C2-C7 sagittal vertical axis (C2-C7 SVA), T1S and T1S-CL, as well as adjacent segment degeneration (ASD), obtained on X-ray. Neck disability index (NDI) and Japanese Orthopedic Association (JOA) score were recorded for evaluating quality of life (QOL). NDI of 20 was defined as the cutoff of QOL. Threshold of T1S-CL was determined by both linear and logistic regression model.

Result

CL, C2-C7 SVA and T1S were insignificant at baseline and all parameters were indifferent at last (P ≥ 0.05). CL and T1S improved at last in both groups (P < 0.05). The incidence of ASD was comparable between groups (P ≥ 0.05). Both groups acquired improvement on NDI and JOA (P < 0.001). There were close correlation among alignment parameters and between parameters and NDI at final follow-up. C2-C7 SVA was independent risk factor for NDI and two regression models predicted C2-C7 SVA with a cutoff of 29.2 mm, corresponded to the threshold on T1S-CL of 20.7°.

Conclusions

It is comparable on alignment reconstruction between SLC and ACP system. The cutoff on C2-C7 SVA with 29.2 mm corresponds to a threshold of T1S-CL with 20.7° in multilevel ACDF.

Introduction

Anterior cervical discectomy and fusion (ACDF) is a world-wide and well-reconstructed strategy for cervical spondylotic myelopathy (CSM) [1]. The modern anterior cage-with-plate system (ACP) consisting of polyetheretherketone cage and titanium plates supports adequate stability of the index segments, while it has been reported, albeit transient, potential disadvantages for its profile and soft tissue dissection [2–3]. The stand-alone self-locked cage (SLC), as the integrated zero-profile cage-plate devices, have been
applied for CSM over a decade [4]. But SLC is not always flawless and debates on complications and efficacy between SLC and ACP have never be silent. Multilevel ACDF, through simple approach and direct decompression, makes up for the weakness of posterior surgery such as laminoplasty (LP) [5]. However, contrasted with single- or double-level, there were much fewer publications on multilevel ACDF with long-term follow-up.

Cervical sagittal alignment, as the partial of spino-pelvic parameters, has been gradually paid attention to as the non-neglectful factors for surgery-programming. The alignment parameters, especially C2-C7 sagittal vertical axis (C2-C7 SVA) and T1 slope (T1S), have been reported in close correlation with quality of life (QOL) while it remains controversial [6–7]. Recently, a concept of T1S minus C2-C7 cervical lordosis (T1S-CL), was proposed, which analogied to the recognized measurement of pelvic incidence (PI) minus lumbar lordosis (LL) in lumbar-pelvic alignment with the threshold of 10° [8]. Although having been defined resonable range of T1S-CL ≤ 20° in some cases, it is obstructing to reach consensus since the balance point of T1S-CL varies in multifarious approaches. Fortunately, it has been proved, with little dispute, loss of CL was initiating agent for alignment disorders, just like LL in lumbar spine and T1S-CL was the key point for evaluating cervical balance [9].

On the one hand, the requirements for proper reconstruction for alignment was perhaps discrepant between LP and ACDF based on the different surgery-indications [5]. On the other hand, the alignment of 3-level ACDF was malleable because of wide surgical exposure, long-segment fusion and sometimes anterior-plating, which has not been quantized with QOL yet. There, the study performed a long-term follow, aiming at (1) comparing cervical alignment and clinical efficacy between SLC and ACP on 3-level ACDF; (2) identifying the relationship between T1S-CL and QOL.

1 Materials And Methods

1.1 Participants

The single-center retrospective comparative study was performed from January 2011 to December 2014. An overall 110 patients with CSM having undergone ACDF were enrolled, who were divided into SLC group with the implants of SLC and ACP group with the system of ACP. The study acquired approval from Ethics Committee of our institution and all participants have signed informed consents. The patients were included required three-level ACDF with at-least 6-week uncontrolling conservation treatment and the operated segments were C3-C6 or C4-C7 by pure either SLC or ACP. Then, the radiographs were intact and clear to be measured. The exclusion criteria were (1) patients with a history cervical spine surgery; (2) cases combined with other disease such as radiculopathy of CS, cervical disc hernia and motor neuron disease; (3) hybrid surgery by inserting SLC with ACP or intervertebral cages with artificial prosthesis; (4) operations for cervical spine tumor, fracture or infection; (5) too fuzzy of radiological parameters to be measured and (6) loss of follow-up or unwilling for consecutive observation.

Eventually, a total of 73 CSM patients with a mean of 6.1-year follow-up (follow-up rate of 66.4%) were included, with 45 patients in SLC group and 28 cases in ACP group. The two cohorts were well-matched in
gender, age and body mass index (BMI) with comparable follow-up period (P ≥ 0.05). The C4-C7 was major operated segments (74.5% vs 77.8%) of both groups (P=0.782). Operation time was shorter in SLC group (P < 0.05) while hemorrhage was comparable (P ≥ 0.05) (Table 1).

1.2 ACDF procedures

A right-sided incision was utilized for both SLC and ACP groups and standard Smith-Robinson approach was performed. Then, three consecutive cages were orderly inserted after complete decompression. Zero-profile-anchored spacer ROI-C (LDR, Troyes, France) were embeded into in SLC group while MC+ (LDR, Troyes, France) or Solis poly-ether-etherketone cages (Stryker, Michigan, USA) combined with anterior plates (DePuySynthes, New Jersey, USA) were utilized as ACP system. All operations were performed by the same senior surgeon and patients were directed to wear collar for 2 months after ACDF, followed by long-term regulating function training in our institution.

1.3 Cervical sagittal alignment

Cervical spine alignment were depicted by 4 radiological parameters. (1) C2-C7 cervical lordosis (CL): the angle was from lower endplate of C2 to lower endplate of C7; (2) C2-C7 SVA: the vertical was from C2 plumb line to posterior margin of the upper endplate of C7; (3) T1S: the angle was from upper endplate of T1 to horizontal line and (4) T1S-CL: was used for cervical spine balance evaluation (Fig 1). In addition, adjacent segment degeneration (ASD) was also in assessment, which was judged by the presence of disk space narrowing more than 50%, new or enlarged osteophytes, endplate sclerosis or increased calcification of the anterior longitudinal ligament [10]. All measurements were obtained from standard lateral X-ray of cervical spine at preoperation (baseline) and last follow-up in December 2019.

The parameters were independently measured by two blind observers. The reliability and reproducibility of inter- and intra-observer were quantitized by intraclass correlation coefficient (ICC). ICC ranged from 0 to 1, where ICC <0.40 suggested a poor reliability and ICC ≥ 0.75 represented a high reliability. The inter-observer ICC showed 0.79 for CL, 0.83 for C2-C7 SVA, 0.75 for T1S and 0.81 for T1S-CL, respectively and intra-observer ICC were 0.85 for CL, 0.87 for C2-C7 SVA, 0.77 for T1S and 0.80 for T1S-CL. All measurements suggested a qualified reliability.

1.4 QOL evaluation

Neck disability index (NDI) and Japanese Orthopedic Association (JOA) score were both recorded at preoperation and final-visit for evaluating QOL. Recovery rate (RR) of JOA was calculated as: RR (%) = (Post-op JOA-Pre-op JOA)/(17-Pre-op JOA)×100. A higher NDI meant a worse QOL and NDI was classified into 5 grades. 0-10 and 10-20 points respectively represented an excellent and good function of cervical spine and 40-50 showed an extreme disabled status [11]. The NDI of 20 was defined as the threshold of nervousological function and QOL after ACDF at last follow-up.

1.5 Statistical analysis
Chi-square analysis were used to compare dichotomous between SLC and ACP group. Independent sample t test and Mann-Whitney U-test were used to for comparisons on continuous variable between groups and paired t test was for variables between baseline and last follow-up. Pearson correlation analysis was applied between radiological parameters and clinical outcomes. Both linear and logistic regression model were established to determine a possible threshold of sagittal parameters, which was most closely correlated to clinical outcomes. A threshold of NDI of 20 points was determined when linear regression analysis performed and cutoff value of predictors by ROC curve was described following logistic regression. The range of T1S-CL was defined corresponding to C2-C7 SVA, which was regarded as a threshold before NDI significantly affected. SPSS Statistics 22.0 (International Business Machines Corporation, Armonk, NY, USA) was the software for analysis and P <0.05 showed statistically significant.

2 Results

2.1 Comparisons between SLC and ACP group

For all cases underwent ACDF, the CL at preoperation and last follow-up were respectively 9.6±12.9° and 14.9±8.6° (P <0.01); the T1S got larger and T1SCL decreased at last compared to baseline (P <0.05), while no statistical change of C2-C7 SVA. At baseline, there were no significances on CL, C2-C7 SVA and T1S (P $\geq$0.05) between SLC and ACP group while T1S-CL was larger in ACP group than SLC (P=0.046). All parameters at last follow-up were of no differences between groups, as well as their changes (all P $\geq$0.05).

For intra-group comparisons, CL got improved at last follow-up compared to that of reoperation in both groups (both P=0.003), so were T1S (P=0.015 and P=0.039, respectively). C2-C7 SVA of both group and T1S-CL at SLC group kept stable contrasted to baseline while T1S-CL in ACP group decreased at last (P=0.021). The incidence of upper and lower ASD were respectively 43.8% and 68.5% and there were no significances of upper or lower ASD between groups (P $\geq$0.05) (Table 2). The number of CL-increasd from SLC (29 cases) and ACP group (23 cases) was insignificant (P=0.104), so were C2-C7 SVA (17 vs 14, P=0.304), T1S (29 vs 22, P=0.201) and T1S-CL (19 vs 8, P=0.240).

The NDI were of no statistical differences between SLC and ACP group both at baseline and final visit (P=0.834 and P=0.485, respectively), as well as their changes (P=0.423); the same as JOA at baseline (P=0.709), at endpoint of follow-up (P=0.775) and RR of JOA (84.6±23.3 vs 82.8±21.3, P=0.776). In total, all cases underwent ACDF from both groups acquired significantly improvement on NDI and JOA compared to baseline (all P <0.001) (Fig 2). There were negative correlation between NDI and JOA at baseline (r=-0.256 and P=0.029) and final visit (r=-0.300, P=0.014).

2.2 Threshold of sagittal parameters after three-level ACDF

Parameters at baseline showed CL positively correlated to T1S while negatively to C2-C7 SVA and T1S-CL (P <0.01). At final visit, CL also positively correlated to T1S, negatively to C2-C7 SVA and T1S-CL (P <0.01); C2-C7 SVA correlated to T1S and T1S-CL, T1S correlated to T1S-CL(P <0.05), the same as their changes (P <0.05) (Table 3, Fig 3). NDI and JOA correlated to C2-C7 SVA at baseline (P <0.05). At last, NDI correlated to CL, C2-C7 SVA and T1S-CL (P <0.01) and JOA correlated to C2-C7 SVA (P=0.011) (Table 4).
There was no influencing factors for NDI at baseline through linear regression analysis, so was JOA at baseline and at last follow-up. When multiple linear regression performed on NDI at final visit, it showed C2-C7 SVA was independent risk factor (P < 0.001) and the fitting formula was NDI = 2.85 + 0.49 × C2-C7 SVA, where the threshold of C2-C7 SVA was 35 mm once substituting NDI of 20 (Table 5). Then CL, C2-C7 SVA and T1S-CL were included as independent factors for forward stepwise multiple logistic regression on final NDI, which revealed that C2-C7 SVA was significant factor (χ² = 34.02, p = 0.001) for NDI (odds ratio = 1.51). The ROC-AUC was 0.955 with Youden index of 0.847 and the cutoff value of C2-C7 SVA was 23.4 mm. Thus, two regression models predicted a threshold C2-C7 SVA of 29.2 mm (Fig 4 (A-B), Fig 5).

T1S and T1S-CL were included as independent variables for multiple linear regression on C2-C7 SVA at final visit while CL was excluded by multicollinearity analysis. Consequently, T1S-CL was the only predictor for C2-C7 SVA (P < 0.001) with relationship of C2-C7 SVA = 8.49 + 0.91 × (T1S-CL). T1S-CL was 22.8° with C2-C7 SVA of 29.2 mm substitution (Table 5). When logistic regression on C2-C7 SVA performed, T1S-CL was significant factor (χ² = 12.26, p = 0.001) with the odds ratio of 1.24. The ROC-AUC was 0.878 (Youden index = 0.625) and the cutoff value of T1S-CL was 18.6°. Therefore, two regression models predicted a threshold T1S-CL of 20.7° (Fig 4 (C-D), Fig 5).

3 Discussion

ACDF was achieved in cases with radiographic signs of instability or no motion at the target levels, with or without facet degeneration. To date, there have been few reports on the biomechanical effect of ACDF involving three or more levels and its clinical indications and contraindications are unclear yet. The main indication of multilevel ACDF due to symptomatic multilevel cervical degenerative disc disease with radiculopathy or myelopathy with strict and accurate reflection of neuro-dysfunction on body-dominating area [3,12]. Whether through ACP or SLC system, 3-level ACDF have been proved reliable and effective on decompression, stability and rebuilding of alignment, especially with the more advanced operating-skill and consequently extended surgical-indications on CSM [13]. The newer launched SLC was approved by some researchers for its zero-profile design, simple inplanation, probable fewer complications such as dysphagia contrasted to former-born ACP system. While it holds debatable since the qualified cost-effectiveness brought by ACP keeps irreplaceable [14]. Therefore, a long-term observation on multilevel SLC versus ACP in this study may support strength on the viewpoints.

In this tudy, the sagittal alignment parameters are comparable between groups after surgery and most are of no significances except T1SCL. Although specific approaches are largely determined by surgeon based on nonuniform surgical-indications, there is a agreement that ACP are likely to be used on cases with straighter spine and imbalanced inclination since kyphotic deformities can be corrected by plate stretching [15], which is one of the somewhat discrepancies on indications between ACP and SLC. The improvement of CL and T1S at final with no significants suggests a well-reconstruction in both groups. As a retrospective study, the change of alignment is induced to extremely avoid selection and reporting bias. The indifference of variable changes between ACP and SLC further consolidates the equivalent efficacy in alignment reestablishment. A main concerning after ACDF was the potential ASD with
increased rigidity. Studies have shown that anterior plate is more likely to accelerate degenerative changes in adjacent segments [16]. However, a meta-analysis performed by Zhang et al. [17] showed no difference in ASD incidence between the SSC and ACP groups with a multilevel ACDF. Our data showed a long-term incidence of 70% on ASD with no intergroup significance, in consistence with Zhang et al. In addition, no case here underwent reoperation for adjacent segment pathology indicated a comparable and limited impact on ASD progression.

The rebuilding of sagittal alignment was emphasized as a main goal in multilevel ACDF and cervical curvation acquires improved in this series after integrating data of the two group with little heterogeneity. Cervical alignment could be corrected by release of anterior tissue, removal of osteophyte, preposess of disc and endplate bed, the shape of cages and sustaining of implants [5,18]. In addition, three levels occupies majority of the overall cervical spine and correction on operated segments is more suitable for stress distribution physiologically [19]. Alberto et al. [20] found a straight cervical spine was related to increased SVA and larger T1SCL, suggesting an interact among parameters. The loss of CL forced an increase of T1S-CL tending to imbalance, imitating the larger PI-LL in loss of LL with pelvis retroversion, ensuing the gravity of head shifts forward to keep horizontal sight with excessive C2-C7 SVA. Cervical balance was evaluated by various factors, where cervical imbalance was defined as T1S > 40° or C2-C7 SVA > 40 mm without consensus [6,21]. Grasso et al. [22] proposed T1S was an important parameter while T1S-CL, like PI-LL, was a better representative than T1S alone, the latter involving two indexes reflecting a further interlocking status. Hyun et al. [9] firstly determined analogous relationship existed in posterior cervical fusion using T1S-CL, where the threshold of C2-C7 SVA was 50 mm corresponded to a T1S-CL value of 26.1°.

There is correlation between NDI and parameters at final visit but not at preoperation. It is considered that QOL of patients with CSM was affected by many factors before surgery, especially the severity of compression on spinal cord and no single factor can absolutely dominate neuro-function. Then the compression is eliminated by the same surgeon, NDI was associated with appropriate sagittal alignment, in this condition, cervical balance status approximates physiological anatomy with most comfortable biomechanics and minimal power consumption, as well as lower tension of paraspinal muscle [23]. The identified relationship of NDI instead of JOA dues to JOA was the patient-reported assessment tool to address each of these domains. Unlike JOA, the NDI is a mix of functional- and pain-status inquiries and more fits the significance of QOL [24-25].

The reasonable range of C2-C7 SVA of 29.2 mm corresponded to T1S-CL of 20.7° is narrower than posterior cervical fusion reported by Hyun et al., which emphasizes the different threshold in various approaches. Staub et al.[26] implied normative CL can be predicted via T1S-CL= 16.5° ± 2° based on 103 patients with cervical spine deformity. It is considered that there were differences between anterior and posterior approach on surgical-indications, internal-fixtions, posterior muscle striping and preservation of ligament complex, where the solid fixation by lateral mass screw and bowstring effect from posterior muscle requires wider range of T1SCL [5,27]. In addition, spinal canal volume changes with flextion-extension posture while posterior such as LP enable a steady enlargement of spinal canal compared to
ACDF [28], allowing larger deviation from neutral alignment without affecting QOL. Other factors such as no debonding on ossification of posterior ligament, disc and osteophyte in posterior approach probably tolerates extensive T1S-CL and C2-C7 SVA. Furthermore, the cutoff value of NDI is 25 in publications while most cases (95.9%) are lower than 25 after ACDF, which will bring reporting bias on defining threshold of T1S-CL and consequently NDI of 20 is adopted.

This study firstly identifies the significance of cervical sagittal parameters in three-level ACDF. Then the cutoff value was quantified in this population through the relationship with QOL, just like PI-LL for evaluation of lumbar-pelvic matching. When T1S-CL ≥20.7° after ACDF, the cervical spine will be involved in imbalance with a straight alignment and a predictive unsatisfactory QOL, which supports strategy for specific program for ACDF [9,29]. The conclusions proposes partial theory for better exploration on the overall sagittal spine-pelvic biomechanics. There are some limitations: Firstly, the sample size of both groups are small and a larger population may support a strength verification. Then, the observation focus on regional parameters on cervical spine instead of the whole spine, which probably bring distinctive points through effect of biomechanics chain. The comparisons are mainly performed on alignments, without other radiological parameters such as range of motion and complications, which were mentioned in publications and not replenished in. The threshold of T1S-CL in this study are just suitable for 3-level ACDF on CSM, the rationality for other types of cervical spine disease need further exploration.

4 Conclusions

Three-level ACDF provides a satisfactory and stable QOL on the treatment of CSM with a mean 6-year follow up. There is comparable capacity on sagittal alignment reconstruction and incidence of ASD between SLC and ACP system. NDI is in close correlation with CL, C2-C7 SVA and T1S-CL after ACDF. In specific, C2-C7 SVA less than 29.2 mm is corresponded to a matching of T1S-CL less than 20.7°, where cervical spine is in balance after ACDF with a better QOL.

Abbreviations

- anterior cervical discectomy and fusion
- ACDF
- cervical spondylotic myelopathy
- CSM
- anterior cage-with-plate system
- ACP
- stand-alone self-locked cage
- SLC
- C2-C7 sagittal vertical axis
- C2-C7 SVA
- T1 slope
- T1S
quality of life
QOL
T1S minus C2-C7 cervical lordosis
T1S-CL
pelvic incidence
PI
lumbar lordosis
LL
C2-C7 cervical lordosis
CL
adjacent segment degeneration
ASD
Neck disability index
NDI
Japanese Orthopedic Association
JOA

Declarations

Ethics approval and consent to participate:
This study has obtained ethics approval and consent of the ethics committee in our hospital.

Consent for publication:
Not applicable

Availability of data and material:
The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Competing interests:
The authors declare that they have no competing interests.

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Tables

Table 1 Demographics between SLC and ACP group
### Table 2 Sagittal alignment parameters between SLC and ACP group at preoperation and last follow-up

| Parameters          | SLC group     | ACP group     | P   |
|---------------------|---------------|---------------|-----|
| CL₁ (°)             | 11.1±12.3     | 5.1±14.1      | 0.086|
| CL₂ (°)             | 15.2±7.8**    | 13.9±11.0**   | 0.633|
| ΔCL (°)             | 4.1±9.7       | 8.8±10.9      | 0.091|
| C2-C7 SVA₁ (mm)     | 17.8±10.6     | 22.0±11.8     | 0.152|
| C2-C7 SVA₂ (mm)     | 16.2±10.6     | 21.1±8.7      | 0.080|
| ΔC2-C7 SVA (mm)     | -1.6±9.0      | -1.0±9.2      | 0.802|
| T1S₁ (°)            | 24.0±7.8      | 23.5±8.9      | 0.825|
| T1S₂ (°)            | 26.5±7.6*     | 26.0±5.5*     | 0.809|
| ΔT1S (°)            | 2.5±7.2       | 2.5±6.8       | 0.993|
| T1S-CL₁ (°)         | 12.9±9.9      | 18.5±10.3     | 0.046|
| T1S-CL₂ (°)         | 11.3±8.8      | 12.1±9.4*     | 0.746|
| ΔT1S-CL (°)         | -1.7±9.5      | -6.4±10.7     | 0.080|
| Upper-ASD           | 22            | 10            | 0.270|
| Lower-ASD           | 31            | 19            | 0.926|

Footnote: SLC: self-locked cage; ACP: anterior cervical cage-with-plate; BMI: body mass index
Footnote: SLC: self-locked cage; ACP: anterior cervical cage-with-plate; CL: C2-C7 cervical lordosis; SVA: sagittal vertical axis; T1S: T1 slope; ASD: adjacent segment degeneration

Δ: the change of same variable at last compared to baseline; ₁: variable at baseline; ₂: variable at last follow-up; *: P <0.05 of same variable at last compared to baseline; **: P <0.01 of same variable at last compared to baseline

Table 3 Correlation analysis among parameters before ACDF and at last follow-up

| Parameters         | CL₁ (°)       | C2-C7 SVA₁ (mm) | T1S₁ (°) |
|--------------------|---------------|-----------------|----------|
|                    | r  | P    | r  | P    | r  | P    |
| C2-C7 SVA₁ (mm)    | -0.386 | 0.001 |          |       |      |       |
| T1S₁ (°)           | 0.607  | 0.000 | 0.090 | 0.450 |      |       |
| T1S-CL₁ (°)        | -0.783 | 0.000 | 0.557 | 0.000 | 0.019 | 0.876 |
| C2-C7 SVA₂ (mm)    | -0.409 | 0.000 |          |       |      |       |
| T1S₂ (°)           | 0.363  | 0.002 | 0.434 | 0.000 |      |       |
| T1S-CL₂ (°)        | -0.673 | 0.000 | 0.735 | 0.000 | 0.445 | 0.000 |
| ΔC2-C7 SVA (mm)    | -0.357 | 0.000 |          |       |      |       |
| ΔT1S (°)           | 0.378  | 0.001 | 0.287 | 0.014 |      |       |
| ΔT1S-CL (°)        | -0.753 | 0.000 | 0.565 | 0.000 | 0.324 | 0.005 |

Footnote: ACDF: anterior cervical discectomy fusion; CL: C2-C7 cervical lordosis; SVA: sagittal vertical axis; T1S: T1 slope

r: correlation coefficient; Δ: the change of same variable at last compared to baseline; ₁: variable at baseline; ₂: variable at last follow-up; ²: correlation analysis among parameters at the same period (eg. C2-C7 SVA₁ vs CL₁ means C2-C7 SVA₁ vs CL₁; ΔT1S vs CL means ΔT1S vs ΔCL)

Table 4 Correlation analysis between parameters and clinical outcomes
| CL\(^{a}\) (°) | C2-C7 SVA\(^{a}\) (mm) | T1S\(^{a}\) (°) | T1S-CL\(^{a}\) (°) |
|----------------|-------------------|--------------|------------------|
| r   | P    | r   | P    | r   | P    | r   | P    |
| NDI\(_1\)   | -0.176 | 0.137 | 0.239 | 0.042 | -0.004 | 0.970 | 0.218 | 0.064 |
| JOA\(_1\)   | -0.051 | 0.667 | -0.240 | 0.041 | -0.065 | 0.587 | 0.014 | 0.908 |
| NDI\(_2\)   | -0.411 | 0.000 | 0.723 | 0.000 | 0.199 | 0.092 | 0.550 | 0.000 |
| JOA\(_2\)   | 0.184  | 0.136 | -0.307 | 0.011 | -0.073 | 0.556 | -0.226 | 0.066 |

Footnote: CL: C2-C7 cervical lordosis; SVA: sagittal vertical axis; T1S: T1 slope; NDI: neck disability index; JOA: Japanese Orthopedic Association

r: correlation coefficient; 1: variable at baseline; 2: variable at last follow-up; \(^{a}\): correlation analysis among parameters at the same period

Table 5 Multiple linear regression analysis for NDI and C2-C7 SVA at last follow-up

| Dependent variable | Coefficient | Unstandardized | Standardized | T  | P |
|--------------------|-------------|----------------|--------------|----|---|
|                   |             | B       | SE       | Beta |    |   |
| NDI                | (constant)  | 2.851   | 2.41     | -2.745 |   |   |
|                   | CL (°)      | -2.404  | 3.386    | -0.71 | 0.480 |
|                   | C2-C7 SVA (mm) | 0.487 | 0.085    | 0.489 | 5.713 | 0.000 |
|                   | T1S (°)     | 2.248   | 3.400    | 2.114 | 0.661 | 0.511 |
|                   | T1S-CL (°)  | -2.332  | 3.385    | -2.761 | -0.689 | 0.493 |
| C2-C7 SVA (mm)    | (constant)  | 8.488   | 3.409    | 2.135 | 0.026 |
|                   | T1S-CL (°)  | 0.834   | 0.110    | 0.911 | 7.574 | 0.000 |
|                   | T1S (°)     | 0.207   | 0.139    | 0.133 | 1.494 | 0.140 |

Footnote: NDI: neck disability index; SVA: sagittal vertical axis; CL: C2-C7 cervical lordosis; T1S: T1 slope

Figures
**Figure 1**

Measurement of alignment parameters on lateral X-ray. (A) the definition of CL and T1S; (B) the definition of C2-C7 SVA
Figure 2

Comparisons on NDI and JOA between SLC and ACP group and between at baseline and at follow-up endpoint. **: P <0.01 between the same variables
Figure 3

Diagram on the interaction among alignment parameters. C2-7 SVA negatively correlated to CL while positively to T1S and T1S-CL. The increase of CL corresponded to a higher T1S to coordinate a maintainance of gravity of head and horizontal sight with a less C2-C7 SVA, the cervical spine was in trend of negative-imblance. Inversely, a straight cervical spine was accompanied with lower T1S and positive cervical-imbalance, where the C2-C7 SVA positively enlarged.
Figure 4

Identification of thresholds on C2-C7 SVA and T1S-CL. (A) scatter diagram on NDI and C2-C7 SVA with linear regression model; (B) ROC curve of NDI and C2-C7 SVA with logistic regression model; (C) scatter diagram on C2-C7 SVA and T1S-CL with linear regression model; (D) ROC curve of C2-C7 SVA and T1S-CL with logistic regression model
Cases on cervical balance and imbalance at follow-up endpoint. (A) 72-year-old male, underwent ACDF from C4-C7 with SLC system 70 months ago. At last follow-up, the lateral X-ray showed CL of 24.3°, T1S of 26.6°, C2-C7 SVA of 14.0 mm with cervical balance (T1S-CL of 2.3°), the final NDI was 4 point; (B) 68-year-old female, underwent ACDF from C4-C7 with SLC system 72 months ago. At last follow-up, the lateral X-ray showed CL of -0.6°, T1S of 29.1°, C2-C7 SVA of 34.1 mm with cervical imbalance (T1S-CL of
29.7°), the final NDI was 22 point; (C) 68-year-old female, underwent ACDF from C3-C6 with ACP system 66 months ago. At last follow-up, the lateral X-ray showed CL of 20.5°, T1S of 27.6°, C2-C7 SVA of 23.1 mm with cervical balance (T1S-CL of 7.1°), the final NDI was 11 point; (D) 64-year-old female, underwent ACDF from C3-C6 with ACP system 72 months ago. At last follow-up, the lateral X-ray showed CL of -8.2°, T1S of 21.1°, C2-C7 SVA of 49.5 mm with cervical balance (T1S-CL of 29.3°), the final NDI was 24 point