Is It Possible To Evaluate the Ideal Cervical Alignment for Each Patient Needing Surgery? An Easy Rule To Determine the Appropriate Cervical Lordosis in Preoperative Planning

Marco Ajello[1], Nicola Marengo[1], Giulia Pilloni[1], Federica Penner[1], Giovanni Vercelli[1], Federico Pecoraro[1], Francesco Zenga[1], Alexander R. Vaccaro[2], Alessandro Ducati[1], Diego Garbossa[1]

■ BACKGROUND: **Cervical sagittal alignment parameters are essential to plan stages of surgery. The aims of this study were to evaluate the relationship between cervical sagittal alignment parameters and surgical outcomes after anterior cervical arthrodesis; to identify parameters linked to a better outcome; to determine the role of the T1 slope, C7 slope, cervical lordosis, and C2-C7 plumb line; and to describe an innovative method to calculate cervical lordosis. A cohort of 70 patients without cervical kyphosis was included in our retrospective study. We analyzed C7 slope, T1 slope, cervical lordosis, and the C2-C7 sagittal vertical axis (SVA). Clinical postoperative outcomes were evaluated with the Neck Disability Index (NDI) and Visual Analog Scale (VAS) score.**

■ RESULTS: **Significant correlation was found between the C2-C7 SVA, C7 slope, T1 slope and the CL/C7 slope. Statistically significant differences were found between group 1 (NDI = 0; VAS = 0) and group 3 (NDI > 17; VAS > 5) regarding C2-C7 SVA ($P = 0.0026$), C7 slope ($P = 0.0014$), T1 slope ($P = 0.0095$) and CL/C7slope ($P = 0.0012$). A value less than 25 mm found in the C2-C7 SVA correlate with positive outcomes. C7 slope correlated with NDI and VAS ($P = 0.0014$). CL/C7 slope ratio is significantly correlated to NDI and VAS scores (ratio: −0.52; $P = 0.0012$). Patients with CL/C7 slope greater than 0.7 had better clinical outcomes.**

■ CONCLUSIONS: **Sagittal parameters are directly correlated with clinical outcome. If C7 slope increases, higher cervical lordosis is necessary to obtain a good outcome. CL/C7 slope (0.7) multiplied by C7 slope can determine the ideal lordosis.**

INTRODUCTION

In the last decade, many studies elucidated the relationship between sagittal alignment and the quality of life after spinal surgery.[1-8] In the past few years, a considerable amount of literature has been published regarding cervical spine alignment and the relationships among different cervical parameters.[9-13] Despite the extensive research, there is still a lack of certainty regarding the optimal amount of cervical lordosis needed to achieve postoperative success. Because of these unclear indications, surgeons usually strive to correct cervical kyphosis to attain an angle as close as possible to neutral.[14] Traditionally, the C-7 sagittal vertical axis (SVA) is used to measure sagittal alignment of the thoracolumbar spine.[15] Thus, current research on cervical spine is trying to adopt similar parameters.[16] More specifically, the C-2 plumb line, chin brow vertical angle, and T1 slope (T1 SL) are increasingly being used.[17,18] To evaluate the effect of cervical alignment in respect to the overall sagittal spine alignment, we use 3-foot spine radiographs.

Moreover, few studies report the relationship between radiographic parameters of the cervical spine and the surgical clinical outcome. Accordingly, the effects of these cervical radiographic measurements on the outcome scores are not nearly as well defined as the global and pelvic parameters are in thoracolumbar deformities.[3,19-21] Similarly, there are few studies[1,2,4] of cervical alignment parameters (mostly represented by lordosis between

Key words
- Cervical degenerative disease
- Cervical lordosis
- Cervical sagittal alignment

Abbreviations and Acronyms
C7 SL: C7 slope
CL: Cervical lordosis
CL/C7 SL: Ratio between CL and C7 SL
NDI: Neck Disability Index
PACS: Picture archiving communication system
SVA: Sagittal vertical axis
T1 SL: T1 slope
VAS: Visual Analog Scale

From the [1]Department of Neuroscience (Neurosurgery Section), University of Turin, Turin, Italy; and [2]Department of Orthopaedic Surgery, The Rothman Institute at Thomas Jefferson University, Philadelphia, Pennsylvania, USA

To whom correspondence should be addressed: Giulia Pilloni, M.D. [E-mail: giulia.pilloni@libero.it]

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C-2 and C-7) related to postoperative clinical outcomes; they all show weak statistical correlations.

OBJECTIVES

Few studies have evaluated the relationship between standing cervical sagittal alignment and postoperative clinical scores for patients without cervical kyphosis receiving single and multilevel anterior cervical fusion. Therefore, our goal is to gain a better understanding of the following parameters:

1. Evaluate the relationship between sagittal alignment of the cervical spine and patient-reported postoperative clinical scores following single and multilevel anterior cervical fusion.
2. Identify the radiographic parameters in the cervical spine that are most predictive of postoperative disability, in particular the influence of T1 slope (T1 SL), cervical lordosis (CL), the C2-C7 SVA, the C7 slope (C7 SL), and the ratio between CL and C7 SL (CL/C7 SL) on postoperative outcomes.
3. Identify a formula to use for predicting the correct amount of lordosis required for a single patient.

MATERIAL AND METHODS

A series of 70 patients who were admitted to our center from 2013 through 2014 for anterior cervical discectomy and fusion were identified retrospectively. Every patient had follow-up within at least 1 year. The population in this study had several diagnoses, such as spondylosis, disc herniation with radiculopathy, and myeloradiculopathy. We excluded from this study all patients with posterior or combined approaches. Among the excluded patients were 4 patients with cervical kyphosis greater than 10 degrees (range, −10 to 35 degrees), because they underwent combined anterior and posterior approaches.

The surgical technique was represented by anterior cervical interbody fusion involving 1, 2, or 3 levels with a plate. All patients had cervical radiographs showing the main skeletal landmarks necessary for accurate measurement. In 15 (21%) of the patients, it was not possible to calculate their T1 slope because the cervical radiographs were limited to C7. The average age was 55 years, with a range of 30–75 years. Both sexes were represented equally: 39 female and 41 male patients. After surgical treatment, Neck Disability Index (NDI), Video Analog Scale (VAS) score, C2-C7 SVA, segmental and total lordosis, C7 and T1 slope, and the ratios between CL/C7SL and CL/T1SL were all analyzed. All measurements were performed digitally using an Infinitt picture archiving communication system (PACS; Infinitt Healthcare, Seoul, South Korea). Lordosis was indicated by a positive value, and kyphosis was indicated by a negative value.

The T1 slope was measured as an angle between a horizontal line and the superior end plate of the T1. The C7 slope was measured as an angle between a horizontal line and the superior end plate of the C7. The C2-C7 SVA represents the distance between C2 and C7 plumb lines. The cervical lordosis was measured using the Cobb angle between the inferior end plate of C2 and the inferior end plate of C7 (Figure 1). Total cervical lordosis and segmental lordosis were calculated using the program Surgimap. Considering the results obtained from CL, C7SL and T1SL, we decided to calculate the ratios between CL/C7SL and CL/T1SL.

The clinical and radiologic follow-up were both obtained at least 12 months after surgery. The mean follow-up was 18 months and ranged between 12 and 30 months. The observers were not blinded.

One of our main goals was to identify a correlation between the NDI/VAS scale and total cervical lordosis, T1 slope (SL), C7 SL, cervical lordosis/C7 SL, CL/T1 SL and C2-C7 SVA. Patients results on postoperative radiographs were evaluated at 1-year follow-up.

First, we calculated the Pearson correlation coefficient between NDI and CL, C7 SL, T1 SL, CL/C7 SL, CL/T1 SL and between VAS and CL, C7 SL, T1 SL, CL/C7 SL, and CL/T1 SL. A value greater than 0.30 and less than −0.30 was considered statistically significant for there to be a correlation.

Second, we divided patients into 3 groups based on the VAS and NDI. Based on VAS score, the first group was composed of patients with VAS score of 0, the second group was characterized by a VAS score of 1–4, and the third group was composed of patients with a VAS score of 5–10. Based on NDI, the first group's NDI score was 0–1, the second group's score was 2–16, and the third group's score was 17–76 (Table 1). In all these groups, we calculated the mean values of C2-C7 SVA, C7 SL, T1 SL, total cervical lordosis, CL/C7 SL and CL/T1 SL, and we determined whether there were any statistically significant differences using the Student t test between groups. The statistical significance level was established at $P < 0.05$. The Fisher exact test was used to analyze 2×2 cross-tabulation tables. Correlation analyses were then performed to examine associations among the selected variables. All statistical analyses were performed using STATISTICA 10 (StatSoft) and SPSS (SPSS Statistics for Windows, version 19.0).

RESULTS

Demographic Data

The study included 70 patients (55 with cervical radiographs including T1). The patient's ages did not significantly differ among the 3 groups. The average age was 52 years (range, 31–81 years). Thirty-one patients (45%) were male, and 39 patients (55%) were female. Most of the patients had one level pathology (n = 38; 54%) followed by two levels (n = 22; 31%), and three levels (n = 11; 15%; Table 2).

Two patients reported postoperative dysphagia that resolved within 3 weeks postoperatively. In addition, 2 patients had postoperative hematoma, 1 of whom required surgical evacuation.

Sixty patients (85%) improved their NDI score, 6 patients (9%) were the same, and 4 patients (6%) worsened. Radiographic information is summarized in Table 3.

Linear Correlation

There was significant correlation among the C2-C7 SVA, C7 SL, T1 SL, CL/C7 SL, and postoperative NDI and VAS scores (Figures 2–5). There was no significant correlation between CL and the CL/T1 SL nor any correlated number of levels treated and postoperative NDI and VAS. Pearson correlation values are summarized in Table 4.

Student *t* Test

Considering the mean NDI values in groups 1 and 3, we found statistically significant differences ($P < 0.05$) in:

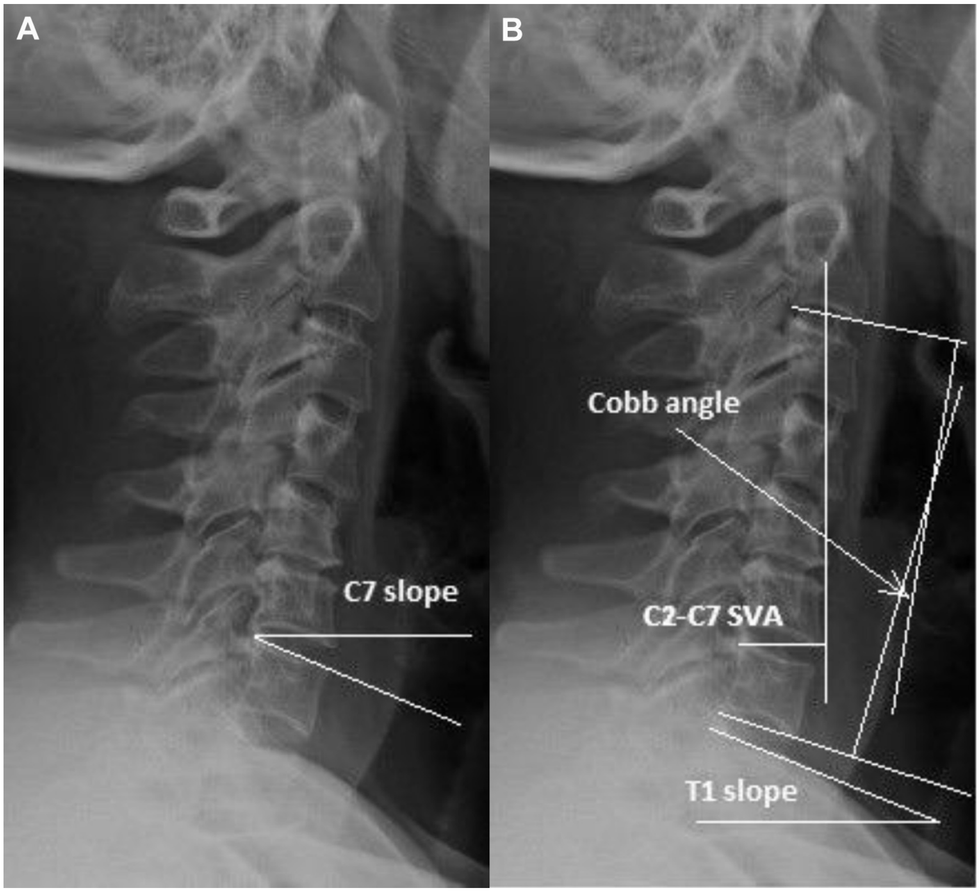

Figure 1. Lateral radiograph demonstrating. (**A**) The angle of C7 slope and (**B**) the angle of the T1 slope, the Cobb angle, and the C2-C7 sagittal vertical axis (SVA).

- C2-C7 SVA ($P = 0.0304$)
- C7 SL ($P = 0.0014$)
- CL/C7 SL ($P = 0.0012$)

Considering the mean values of VAS in groups 1 and 3, we found statistically significant differences ($P < 0.05$) in:

- C2-C7 SVA ($P < 0.0026$)
- C7 SL ($P = 0.0324$)
- T1 SL ($P = 0.0095$)

Table 1. All Patients were Divided into Three Groups Based on VAS Scale and NDI

	Group 1	Group 2	Group 3
Neck Disability Index	0–1	2–16	17–76
Visual Analog Scale	0	1–4	5–10

Table 2. Patient Information: Number of Levels Affected of the 70 Patients Selected for This Study

Age (years)	52 ± 21
NDI pre	31.9
NDI post	13.9
VAS pre	6
VAS post	2
Number of levels	
1	38 (54%)
2	22 (31%)
3	11 (15%)
Sex	
Male	31 (45%)
Female	39 (55%)

Table 3. Average Radiographic Information

Parameters Involved	Number of Patients	Average Radiographic Information
C2-C7 SVA	70 pz	26.34 mm
C2-C7 Lordosis	70 pz	15 degrees
C7 SL	70 pz	26 degrees
T1 SL	55 pz	29 degrees
CL/C7 SL	70 pz	0.57 degrees

SVA, Sagittal vertical axis; SL, slope; CL, cervical lordosis; pz, patients.

- CL/C7 SL ($P = 0.0196$)

A statistically significant ($P > 0.05$) difference was not obtained comparing the NDI mean values of:

- CL ($P = 0.1205$)
- T1 SL ($P = 0.0569$)
- CL/T1 SL ($P = 0.2999$)

A statistically significant ($P > 0.05$) difference was not obtained comparing the VAS mean values of:

- CL ($P > 0.3209$)
- CL/T1 SL ($P = 0.4918$)

No statistically significant difference was found between groups 1 and 2 for all parameters.

The main P values between groups 1 and 3 are summarized in Table 5 (see Figures 1–4).

DISCUSSION

Simply obtaining a better sagittal alignment was not the endpoint of our study. Because there is no agreement in the literature regarding what the correct cervical sagittal alignment should be, we opted not to divide our groups according to the alignment itself. Accordingly, the patients were separated based on their clinical postoperative scores. Once separated, we tried to find a correlation between the sagittal alignment and an easy indication to help understand what the ideal alignment should be to obtain optimal lordosis in each patient. This procedure helped us to ascertain a practical rule for calculating the correct cervical lordosis.

Our data suggest that multiple cervical sagittal alignment parameters are associated with NDI and VAS scores in postoperative patients. To demonstrate our hypothesis, we first conducted a Pearson correlation coefficient controlling all of the relevant radiographic and clinical variables. Next, we performed tree subgroup analyses.

Both the C7 SL and T1 SL were evaluated in our statistical analysis. In our series, the T1 SL and C7 SL values did not significantly differ. For anatomic reasons, the C7 slope seemed to have a simplified calculation; thus, the C7 SL appeared to be a good alternative instead of the T1 SL for calculating the ideal lordosis. In 21% of our patients' images, we encountered technical issues calculating the T1 slope. This parameter was already studied by Boissière et al.[22,23] who already showed a relation between C7 SL and CL. In our series this parameter was found to be highly related to postoperative outcome.

In our linear correlation, we found that increased C2-C7 SVA, T1 SL, and C7 SL were correlated with increased NDI and VAS score. In the analysis of 3 groups, we found that patients with a postoperative C2-C7 SVA of 24 ± 10 mm have better outcome in terms of VAS and NDI than do patients with a C2-C7 SVA of 38 mm ($P = 0.0026$); patients with a C7 SL of 24 degrees had better outcomes than did patients with higher a C7 SL value (32 degrees; $P = 0.0014$). The T1 slope was related to the postoperative outcome as well; patients with a T1 SL of 25 degrees had better outcome in terms of VAS than did patients with a higher T1 SL value (33 degrees; $P = 0.0095$).

The other variables, including cervical lordosis, were not significant predictors of postoperative clinical outcome ($r = -0.11$). Interestingly, in the 3 subgroup analyses, there was no significant difference between CL in patients with low and high NDI and VAS scores ($P = 0.3209$).

Having obtained the aforementioned results, we decided to study the ratio between CL and C7 SL and between the CL and T1

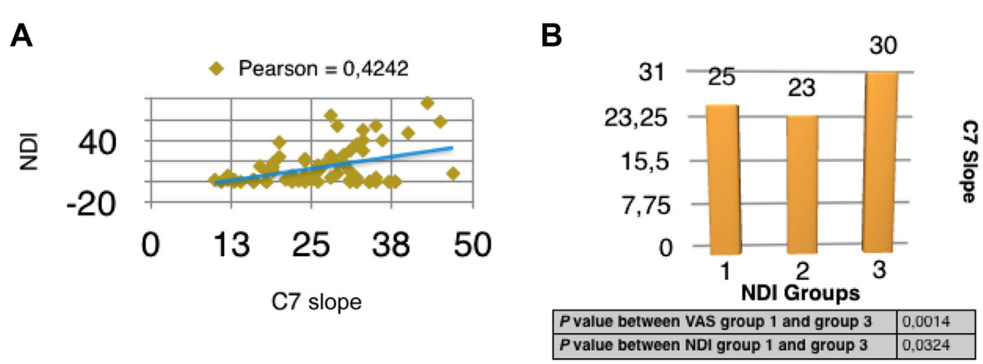

Figure 2. (**A**) Linear correlation between increase of C7 SL and increase of Neck Disability Index (NDI) values and (**B**) average of C7 slope (degrees) in the 3 NDI groups with *P* value between groups 1 and 3.

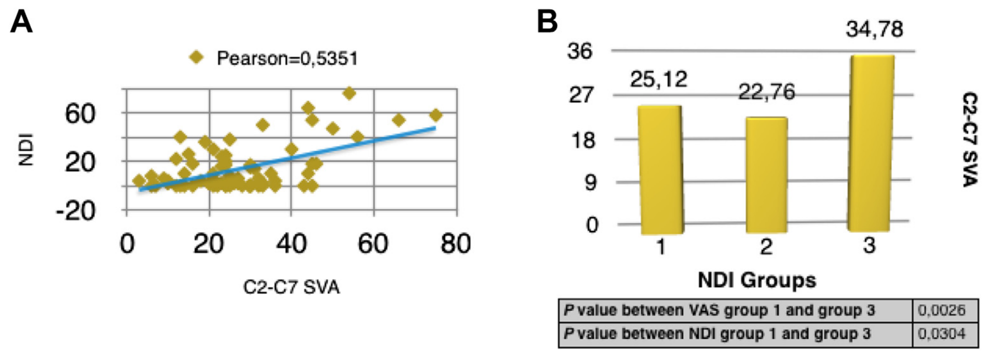

Figure 3. (**A**) Linear correlation between increase of C2-C7 SVA and increase of Neck Disability Index (NDI) values and (**B**) average of C2-C7 sagittal vertical axis (SVA; mm) in the 3 NDI groups with *P* value between groups 1 and 3.

SL to correlate this value with postoperative NDI and VAS values. We found a strong linear correlation between the increasing of CL/C7SL ratio and clinical outcome ($r = -0.5211$).

More specifically, the two groups with low postoperative VAS and NDI (groups 1 and 2) have CL/C7 SL ratios of 0.7 (NDI) and 0.7 (VAS), and the group with high VAS and NDI (group 3) has a ratio of 0.33. We found this difference to be statistically significant ($P = 0.0012$; **Figure 6**).

The results of our linear correlation showed that decreasing CL/C7 SL and increasing C2-C7 SVA, C7 SL and T1 SL were independent predictors of high postoperative NDI and VAS. Our results of linear correlation confirmed that sagittal alignment is an important predictor of postoperative disability.

From our results, we deduce that the C7 slope might be (1) another important parameter that is easy to calculate and distinguished from T1 SL and C2-C7 SVA, affecting the physiological sagittal alignment of the cervical spine, and (2) that the CL/C7 SL ratio (0.7) found in the groups with good outcome can be used as a coefficient to calculate the approximate CL needed during a cervical surgery starting from the C7 SL. In a single-level discopathy, the gold standard is the anterior interbody fusion that usually allows us to reach the maximal lordosis needed in that level. In a multiple-level surgery such as spondylotic myelopathy, we should consider this coefficient to evaluate the total amount of lordosis needed and choose the correct approach that allows us to reach it. Kim et al.[24] showed that a high value of the T1 SL is a predictor of kyphotic alignment change after laminoplasty in patients with cervical myelopathy. In such patients, an anterior–posterior combined approach or a posterior fusion with intraoperative hyperextension should be evaluated. Other reports show that the T1 SL might[11,24,25] have a role in cervical and global alignment. It is suggested that patients with a steep T1 SL are more likely to have thoracic kyphosis or lumbar hypolordosis.[11,24,25] For this reason, Knott et al.[25] recommend using full-standing radiographs when the T1 slope is less than 13 degrees or greater than 25 degrees.[25] The normal range of the T1 slope suggested by other authors is 22–32

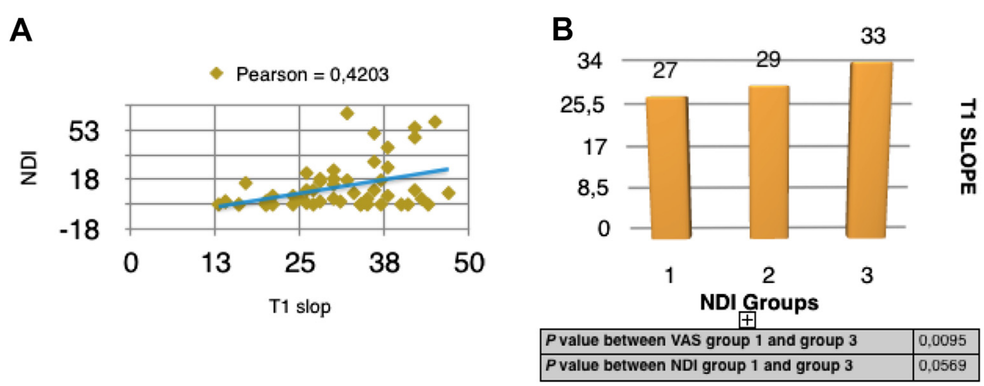

Figure 4. (**A**) Linear correlation between increase of T1 slope and increase of Neck Disability Index (NDI) values and (**B**) average of T1 slope (degrees) in the 3 NDI groups with *P* value between groups 1 and 3.

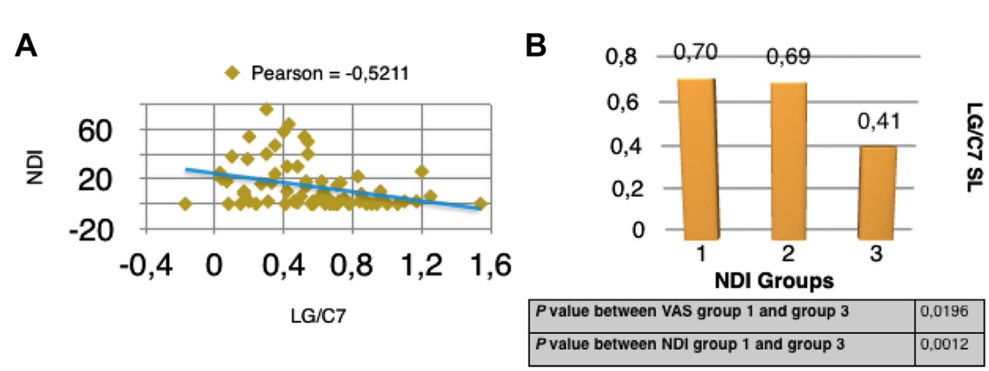

Figure 5. (**A**) Linear correlation between increase of the ratio cervical lordosis (CL)/C7 SL and decrease of Neck Disability Index (NDI) values and (**B**) average of CL/C7 slope in the 3 NDI groups with *P* value between groups 1 and 3.

degrees.[26,27] In such cases, if a spinopelvic imbalance is discovered, a compelling issue to address is to determine what should be treated first—the cervical or the lower spine.

We are aware of the limits of this study. The data represent a heterogeneous patient population, and we included in this group patients presenting with myelopathy or radiculopathy, and patients treated with single, double, or tree-level anterior interbody fusion.

The alignment is only one of several variables that can influence the clinical outcomes after cervical fusion. The right indications, the choice of approach, the instrumentation choices, and an adequate decompression all influence the clinical outcomes after surgery. However, our data show the relationship between sagittal alignment and postoperative clinical outcomes, even in patients without obvious deformity, and suggest that spinal surgeons should consider alignment parameter when planning spinal cervical surgery.

Because CL/C7 SL and C2-C7 SVA seem to be strong predictors of the clinical outcome, we believe that spine surgeons should obtain standing cervical films and should evaluate the relationship between C7 SL, T1 SL, CL, and C2-C7 SVA in all the patients that are affected by cervical pathology, even without obvious deformity (Figure 5).

We think that a larger study is required to better explore and analyze these relationships in preoperative and postoperative patients and in asymptomatic populations. A larger study could help us to identify better targets for C7SL, TS, CL, SVA, and C7 SL/CL.

In conclusion, C2-C7 SVA, C7 SL, T1 SL and CL/C7 SL are strongly associated with the clinical outcome. Increasing C2-C7 SVA and C7 and T1 SL is linked with increasing NDI and VAS scores. Changes in CL alone are not correlated with any clinical changes. Postoperative CL is probably not correlated with clinical outcomes. The reason could be that CL has to be related to more fixed parameters, such as C7 SL or T1 SL. We demonstrated that decreasing CL, if accompanied by decreasing C7 SL, is not correlated with bad clinical outcome (Figure 5). Increasing C7 SL and T1 SL, if accompanied by increasing CL, is not related to bad clinical outcome either. A higher CL/C7 SL ratio (0.7) is correlated with better outcome. In addition, the use of 0.7 as a coefficient to multiply with C7 SL could be useful to calculate the correct amount of lordosis needed by every single

Table 4. Correlation of Postoperative Sagittal Alignment with Neck Disability Index and Visual Analog Scale for All Patients with Pearson Coefficient

	Visual Analog Scale	Neck Disability Index
C2-C7 SVA	0.3851*	0.5351*
CL	−0.0505	−0.1178
C7 SL	0.4199*	0.4242*
T1 SL	0.3515*	0.4203*
CL/T1 SL	−0.0466	−0.1632
CL/C7 SL	−0.3040*	−0.3311*
No. of Levels	−0.15	−0.22

SVA, Sagittal vertical axis; CL, cervical lordosis; SL, slope; CL/T1 SL, CL T1 slope ratio; CL/C7 SL, CL C7 SL ratio.
*Significant correlation ($r < -0.3$; $r > 0.3$).

Table 5. *P* Value Calculated with Student *t* Test Between Groups 1 and 3

Parameter Involved	VAS Group 1–3	NDI Group 1–3
SVA	0.0026*	0.0304*
Lordosi	0.3209	0.1204
C7 SL	0.0324*	0.0014*
T1 SL	0.0095*	0.0569*
C7/SL lordosi	0.0196*	0.0012*
T1/SL lordosi	0.4918	0.2999

Visual Analog Scale Group 1 = 0; Group 3 > 5. Neck Disability Index Group 1 = 0–1; Group 3 > 17.
SVA, Sagittal vertical axis; SL, slope.
*Significant changes ($P < 0.05$).

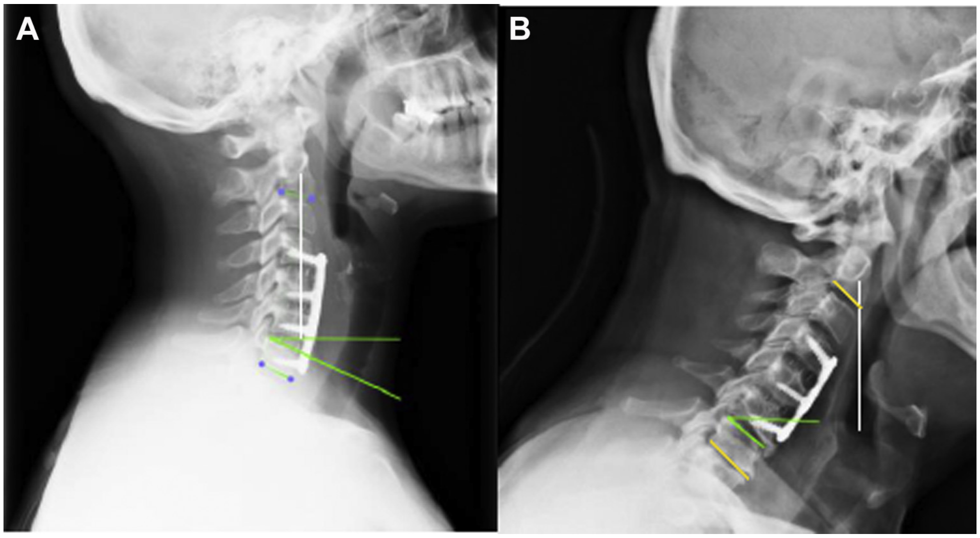

Figure 6. Lateral radiographs of 2 patients demonstrate how increased cervical lordosis (CL)/C7 ratio and cervical C2-C7 sagittal vertical axis (SVA) relates to poor health-related quality of life measures. (**A**) Normal cervical SVA of 20.9 mm and CL/C7 SL of 0.7 (CL =17 degrees; C7 SL = 24 degrees) with an NDI value of 2 and Visual Analog Scale (VAS) value of 0 (no disability). (**B**) Increased cervical SVA of 59.2 mm and CL/C7 SL of 0.26 (CL = 10 degrees; C7 SL = 38 degrees) with an NDI value of 37 and a VAS value of 6 (severe disability).

patient starting from their C7 SL or T1 SL. Low CL/C7 SL along with high C2-C7 SVA were independent predictors of high postoperative NDI and VAS values.

Taken together, these findings add to the existing evidence in the literature highlighting the fundamental role of cervical alignment that is related to a healthy quality of life.[28-30]

CONCLUSIONS

As we learned from thoracolumbar spine surgery, we cannot exclude the sagittal parameter when planning spinal surgery. We know that the spinopelvic parameter is more defined and widely used than the aforementioned correlations. The spinopelvic parameters are studied and used mostly on patients with preexisting sagittal imbalance and deformity, thus strongly correlating with the quality of life.[1,3,10,31] In our study, there was a strong correlation between C2-C7 SVA, CL/C7 SL, C7 SL, and T1 SL and postoperative clinical outcome, even in patients without cervical deformity.

What we can learn from our study is that:

- In patients without significant kyphosis, regional cervical alignment should be evaluated preoperatively with standing cervical radiographs for appropriate operative planning. Patients with a high value of T1 should be evaluated with full-standing radiographs to exclude bigger deformities.
- When performing cervical surgery, our findings could help with planning the most appropriate strategy and approach in patients with or without evident deformity.
- The C2-C7 SVA is correlated to postoperative NDI and VAS values. A value of C2-C7 SVA less than 25 mm correlates with better outcomes.
- The CL/C7 SL is correlated to postoperative NDI and VAS. The T1 and C7 inclination can determine the amount of subaxial lordosis required to have a good clinical outcome. We suggest that the coefficient of 0.7 multiplied by the C7 slope could be used in the preoperative planning to determine the ideal lordosis required for each patient.
- Larger and prospective studies are required to define a better and stronger relationship between sagittal alignment parameters and clinical postoperative outcome. Our results may be useful as a baseline for further studies of the sagittal balance of the cervical spine.

REFERENCES

1. Djurasovic M, Glassman SD. Correlation of radiographic and clinical findings in spinal deformities. *Neurosurg Clin N Am*. 2007;18:223-227.

2. Glassman SD, Berven S, Bridwell K, Horton W, Dimar JR. Correlation of radiographic parameters and clinical symptoms in adult scoliosis. *Spine (Phila Pa 1976)*. 2005;30:682-688.

3. Glassman SD, Bridwell K, Dimar JR, Horton W, Berven S, Schwab F. The impact of positive sagittal balance in adult spinal deformity. *Spine (Phila Pa 1976)*. 2005;30:2024-2029.

4. Gum JL, Glassman SD, Douglas LR, Carreon LY. Correlation between cervical spine sagittal alignment and clinical outcome after anterior cervical

discectomy and fusion. *Am J Orthop (Belle Mead NJ)*. 2012;41:E81-E84.

5. Jackson RP, Hales C. Congruent spinopelvic alignment on standing lateral radiographs of adult volunteers. *Spine (Phila Pa 1976)*. 2000;25: 2808-2815.

6. Lafage V, Schwab F, Skalli W, Hawkinson N, Gagey PM, Ondra S, et al. Standing balance and sagittal plane spinal deformity: analysis of spinopelvic and gravity line parameters. *Spine (Phila Pa 1976)*. 2008;33:1572-1578.

7. Lafage V, Schwab F, Patel A, Hawkinson N, Farcy JP. Pelvic tilt and truncal inclination: two key radiographic parameters in the setting of adults with spinal deformity. *Spine (Phila Pa 1976)*. 2009; 34:E599-E606.

8. Mac-Thiong JM, Transfeldt EE, Mehbod AA, Perra JH, Denis F, Garvey TA, et al. Can c7 plumbline and gravity line predict health related quality of life in adult scoliosis? *Spine (Phila Pa 1976)*. 2009;34:E519-E527.

9. Schwab F, Patel A, Ungar B, Farcy JP, Lafage V. Adult spinal deformity-postoperative standing imbalance: how much can you tolerate? An overview of key parameters in assessing alignment and planning corrective surgery. *Spine (Phila Pa 1976)*. 2010;35:2224-2231.

10. Protopsaltis T, Schwab F, Bronsard N, Smith JS, Klineberg E, Mundis G, et al. The T1 pelvic angle, a novel radiographic measure of global sagittal deformity, accounts for both spinal inclination and pelvic tilt and correlates with health-related quality of life. *J Bone Joint Surg Am*. 2014;96: 1631-1640.

11. Lee SH, Kim KT, Seo EM, Suk KS, Kwack YH, Son ES. The influence of thoracic inlet alignment on the craniocervical sagittal balance in asymptomatic adults. *J Spinal Disord Tech*. 2012;25: E41-E47.

12. Tang JA, Scheer JK, Smith JS, Deviren V, Bess S, Hart RA, et al. The impact of standing regional cervical sagittal alignment on outcomes in posterior cervical fusion surgery. *Neurosurgery*. 2012;71: 662-669 [discussion: 669].

13. Protopsaltis TS, Terran JS, Bronsard N, et al. T1 slope minus cervical lordosis (TS-CL), the cervical analog of PI-LL defines cervical sagittal deformity in patients undergoing thoracolumbar osteotomy. Abstract presented at the 2013 Annual Meeting of the Cervical Spine Research Society in Los Angeles, CA, December 5-7, 2013.

14. Steinmetz MP, Stewart TJ, Kager CD, Benzel EC, Vaccaro AR. Cervical deformity correction. *Neurosurgery*. 2007;60(1 Suppl 1):S90-S97.

15. Schwab FJ, Lafage V, Farcy JP, Bridwell KH, Glassman S, Shainline MR. Predicting outcome and complications in the surgical treatment of adult scoliosis. *Spine (Phila Pa 1976)*. 2008;33: 2243-2247.

16. Van Royen BJ, Toussaint HM, Kingma I, Bot SD, Caspers M, Harlaar J, et al. Accuracy of the sagittal vertical axis in a standing lateral radiograph as a measurement of balance in spinal deformities. *Eur Spine J*. 1998;7:408-412.

17. Hwang SW, Samdani AF, Tantorski M, Cahill P, Nydick J, Fine A, et al. Cervical sagittal plane decompensation after surgery for adolescent idiopathic scoliosis: an effect imparted by postoperative thoracic hypokyphosis. Clinical article. *J Neurosurg Spine*. 2011;15:491-496.

18. Langeloo DD, Journee HL, Pavlov PW, de Kleuver M. Cervical osteotomy in ankylosing spondylitis: evaluation of new developments. *Eur Spine J*. 2006;15:493-500.

19. Bridwell KH, Baldus C, Berven S, Edwards C, Glassman S, Hamill C, et al. Changes in radiographic and clinical outcomes with primary treatment adult spinal deformity surgeries from two years to three- to five-years follow-up. *Spine (Phila Pa 1976)*. 2010;35:1849-1854.

20. Schwab F, Farcy JP, Bridwell K, Berven S, Glassman S, Harrast J, et al. A clinical impact classification of scoliosis in the adult. *Spine (Phila Pa 1976)*. 2006;31:2109-2114.

21. Schwab FJ, Smith VA, Biserni M, Gamez L, Farcy JP, Pagala M. Adult scoliosis: a quantitative radiographic and clinical analysis. *Spine (Phila Pa 1976)*. 2002;27:387-392.

22. Boissièr L, Bernard J, Vital JM, Pointillart V, Mariey R, Gille O, et al. Cervical spine balance: postoperative radiologic changes in adult scoliosis surgery. *Eur Spine J*. 2015;24:1356-1361.

23. Núñez-Pereira S, Hitzl W, Bullmann V, Meier O, Koller H. Sagittal balance of the cervical spine: an analysis of occipitocervical and spinopelvic interdependence, with C-7 slope as a marker of cervical and spinopelvic alignment. *J Neurosurg Spine*. 2015; 23:16-23.

24. Kim TH, Lee SY, Kim YC, Park MS, Kim SW. T1 slope as a predictor of kyphotic alignment change after laminoplasty in patients with cervical Myelopathy. *Spine (Phila Pa 1976)*. 2013;38: E992-E997.

25. Knott PT, Mardjetko SM, Techy F. The use of the T1 sagittal angle in predicting overall sagittal balance of the spine. *Spine J*. 2010;10:994-998.

26. Ames CP, Blondel B, Scheer JK, Schwab FJ, Le Huec JC, Massicotte EM, et al. Cervical radiographical alignment: comprehensive assessment techniques and potential importance in cervical myelopathy. *Spine (Phila Pa 1976)*. 2013;38(22 Suppl 1):S149-S160.

27. Hann S, Chalouhi N, Madinemi R, Vaccaro A. An algorithmic strategy for selecting a surgical approach in cervical deformity correction. *Neurosurg Focus*. 2014;36:E5.

28. Iida H, Tachibana S. Spinal cord intramedullary pressure: direct cord traction test. *Neurol Med Chir (Tokyo)*. 1995;35:75-77.

29. Gangnet N, Pomero V, Dumas R, Skalli W, Vital JM. Variability of the spine and pelvis location with respect to the gravity line: a three-dimensional stereoradiographic study using a force platform. *Surg Radiol Anat*. 2003;25:424-433.

30. Schwab F, Lafage V, Boyce R, Skalli W, Farcy JP. Gravity line analysis in adult volunteers: age-related correlation with spinal parameters, pelvic parameters, and foot position. *Spine (Phila Pa 1976)*. 2006;31:E959-E967.

31. Bridwell KH, Baldus C, Berven S, Edwards C, Glassman S, Hamill C, et al. Changes in radiographic and clinical outcomes with primary treatment adult spinal deformity surgeries from two years to three to five years follow-up. *Spine (Phila Pa 1976)*. 2010;35:1849-1854.

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