Relationship Between T1 Slope and Cervical Alignment Following Multilevel Posterior Cervical Fusion Surgery

Impact of T1 Slope Minus Cervical Lordosis

Seung-Jae Hyun, MD, PhD, Ki-Jeong Kim, MD, PhD, Tae-Ahn Jahng, MD, PhD, and Hyun-Jib Kim, MD, PhD

Study Design. Retrospective study.
Objective. To assess the relationship between sagittal alignment of the cervical spine and patient-reported health-related quality-of-life scores following multilevel posterior cervical fusion, and to explore whether an analogous relationship exists in the cervical spine using T1 slope minus C2-C7 lordosis (T1S-CL).

Summary of Background Data. A recent study demonstrated that, similar to the thoracolumbar spine, the severity of disability increases with sagittal malalignment following cervical reconstruction surgery.

Methods. From 2007 to 2013, 38 consecutive patients underwent multilevel posterior cervical fusion for cervical stenosis, myelopathy, and deformities. Radiographic measurements included C0-C2 lordosis, C2-C7 lordosis, C2-C7 sagittal vertical axis (SVA), T1 slope, and T1S-CL. Pearson correlation coefficients were calculated between pairs of radiographic measures and health-related quality-of-life.

Results. C2-C7 SVA positively correlated with neck disability index (NDI) scores ($r = 0.495$). C2-C7 lordosis ($P = 0.001$) and T1S-CL ($P = 0.002$) changes correlated with NDI score changes after surgery. For significant correlations between C2-C7 SVA and NDI scores, regression models predicted a threshold C2-C7 SVA value of 50 mm, beyond which correlations were most significant. The T1S-CL also correlated positively with C2-C7 SVA and NDI scores ($r = 0.871$ and $r = 0.470$, respectively). Results of the regression analysis indicated that a C2-C7 SVA value of 50 mm corresponded to a T1S-CL value of 26.1°.

Conclusion. This study showed that disability of the neck increased with cervical sagittal malalignment following surgical reconstruction and a greater T1S-CL mismatch was associated with a greater degree of cervical malalignment. Specifically, a mismatch greater than 26.1° corresponded to positive cervical sagittal malalignment, defined as C2-C7 SVA greater than 50 mm.

Key words: cervical lordosis, health-related quality-of-life, posterior cervical fusion, sagittal alignment, spinal deformity, T1 slope.

Level of Evidence: 3

Spine 2016;41:E396–E402

 Sagittal vertical axis (SVA) values are standard measurements taken to assess deformity in the thoracolumbar spine. Previous researchers have concluded that positive sagittal malalignment, defined as a C7 plumb line greater than 50 mm anterior to the posterosuperior aspect of the sacrum, is associated with a deterioration of quality of life in patients with adult spinal deformity. Specially, one significant predictor of disability is a mismatch greater than 9° between lumbar lordosis (LL) and pelvic incidence (PI). A recent study demonstrated that, similar to the thoracolumbar spine, the severity of disability increases with positive sagittal malalignment following cervical reconstruction surgery. It was suggested that a C2-C7 SVA value of 40 mm was a threshold, beyond which neck disability index (NDI) was significantly adversely affected.

The T1 slope has been suggested previously as an important factor influencing overall spinal sagittal alignment, and increasing T1 slope has been shown to correlate significantly with greater sagittal malalignment of the dens. In parallel with the observations in the thoracolumbar spine, we evaluated the association of T1 slope with alignment...
parameters of the cervical spine. In the current study, we used the T1 slope minus C2-C7 lordosis (T1S-CL), the cervical analog to PI-LL, to evaluate the association of the cervical analog with alignment parameters of the cervical spine after multilevel cervical fusion. In this study, we aimed to confirm the relationship between the sagittal alignment of the cervical spine and patient-reported health-related quality-of-life (HRQOL) scores following multilevel posterior cervical fusion in an Asian patient population, and to explore whether an analogous relationship existed in the cervical spine using the T1S-CL.

MATERIALS AND METHODS

After obtaining institutional review board approval (No. L-2014–189), a retrospective analysis of radiographic and clinical results was performed for patients who underwent single-stage, multilevel (3 or less levels) posterior cervical fusion for spondylotic myelo- and/or radiculopathy, cervical stenosis by ossification of the posterior longitudinal ligament, degenerative disc disorders, and deformities. Patients having trauma, tumor, or infection of the spine and where it was difficult to determine the T1 slope were excluded. Neural decompression by laminectomy and instrumented fusion was our operative technique in this series. No spinal osteotomy case such as Smith-Peterson type or pedicle subtraction osteotomy was enrolled in this study. Deformity or ossification of the posterior longitudinal ligament patients requiring circumferential approach were excluded from this study. From 2007 to 2013, 81 patients were treated with a posterior cervical fusion for these causes. Of them, 41 received three or more levels of fusion. It was difficult in three patients to accurately determine the T1 slope. Thus, finally, 38 patients (M/F = 25/13, 61 ± 10 years old) with intermediate follow-up period (6 months) was selected to exclude several long-term risks, such as symptomatic pseudarthrosis or junctional disorders.

Pre- and postoperative lateral standing plain radiographs were obtained in a neutral standing position and instructed to look straight ahead with hips and knees extendedly. The following parameters were evaluated (Figure 1): C0-C2 lordosis (the angle between the McRae line and the C2 lower end plate was measured using the Cobb method); C2-C7 lordosis (the angle created by a line parallel to the inferior aspect of the C2 body and a line parallel to that of the C7 body was measured on neutral lateral radiographs); C2-C7 SVA (distance between C2 plumb line and posterior superior endplate of C7, with positive sagittal alignment defined as an anterior deviation); T1 slope (the angle between horizontal line and superior endplate of T1). SVA indicates sagittal vertical axis.

Two self-assessment HRQOL measures were obtained from each patient: NDI and a visual analog pain scale (VAS) for axial neck and arm pain. To measure the intra- and interobserver reliability of radiographic parameter, two spine surgeons independently performed the measurements three times. There was at least a 2 weeks interval between each measurement. All radiological measurements were made using a picture-archiving and communication system, INFINIT PACS (INFINITT Healthcare Co., Ltd., Seoul, Korea).

Statistical analyses were performed using the SPSS software (ver. 21.0, 2012; SPSS, Inc., Chicago, IL) to determine correlations between HRQOL and radiographic measurements. Pearson correlation coefficients were calculated for radiographic parameters and HRQOL scores. A $P < 0.05$ was considered statistically significant. Correlation analyses using both a linear and a logistic regression model were performed to determine a possible threshold of radiographic parameters for which the correlation with HRQOL scores was most significant. For the linear regression, correlations were evaluated to determine a threshold of disability.
TABLE 1. Comparison of Cervical Measurements to Normative Data

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Asymptomatic</th>
<th>Preoperative</th>
<th>Postoperative</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>C0-C2 lordosis (degrees)</td>
<td>22.4 ± 8.5</td>
<td>38.2 ± 9.5</td>
<td>41.0 ± 9.7</td>
<td>0.018</td>
</tr>
<tr>
<td>C2-C7 lordosis (degrees)</td>
<td>9.9 ± 12.5</td>
<td>10.1 ± 8.1</td>
<td>6.0 ± 8.7</td>
<td>0.001</td>
</tr>
<tr>
<td>C2-C7 SVA (mm)</td>
<td>16.8 ± 11.2</td>
<td>30.6 ± 13.3</td>
<td>33.6 ± 17.5</td>
<td>0.005</td>
</tr>
<tr>
<td>T1 slope (degrees)</td>
<td>25.7 ± 6.4</td>
<td>25.7 ± 6.9</td>
<td>23.2 ± 8.0</td>
<td>0.202</td>
</tr>
<tr>
<td>T1S-CL (°)</td>
<td>15.8 ± 9.4</td>
<td>15.6 ± 8.4</td>
<td>17.1 ± 10.3</td>
<td>0.002</td>
</tr>
<tr>
<td>Neck disability index</td>
<td>23.8 ± 11.7</td>
<td>18.1 ± 11.2</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The values are given as mean ± standard deviation. SVA indicates sagittal vertical axis; T1S-CL, T1 slope minus C2-C7 lordosis. A P value means clinical impacts of radiographic parameter changes on neck disability index score changes. Mean values of cervical lordosis and SVA compared with normative data from asymptomatic patients.

RESULTS

In total, 38 patients (M = 25, F = 13) were identified, and their mean age was 61 ± 10 (range, 23–83) years. The surgical indications for multilevel cervical fusion included cervical spondylotic myelopathy and/or radiculopathy (n = 17), cervical stenosis by ossification of the posterior longitudinal ligament (n = 17), degenerative disc disorders (n = 2), and deformity (n = 2). The number of levels fused ranged from three to seven (mean, 3.4 ± 0.8) levels. The number of the fusion levels had no correlation with radiographic parameters and HRQOL (P > 0.05). The average follow-up period for which radiographic measurements and HRQOL scores were obtained postoperatively was 6.2 ± 0.5 months.

C0-C2 lordosis angles ranged from 25.0 to 63.1° with a mean of 41.0 ± 9.7°. C2-C7 lordosis angles ranged from −12.8 to 22.5° with a mean of 6.0 ± 8.7° (negative value means kyphotic angle). Total cervical lordosis (summation of C0-C2 lordosis and C2-C7 lordosis) ranged from 31.9 to 63.3° with a mean of 47.0 ± 8.5°. C0-C2 lordosis constituted 85.4% of total cervical lordosis. C2-C7 SVA ranged from 2.1 to 75.4 mm with a mean of 33.6 ± 17.5 mm. The T1 slope ranged from 10.3 to 46.1, with a mean 23.2 ± 8.0°. T1S-CL ranged from −9.0 to 39.6, with a mean 17.1 ± 10.3°. Table 1 summarizes the pre- and postoperative values of radiographic measurements/NDI scores in comparison with normative data from asymptomatic patients. On radiographic evaluation, the assessment of intra-observer and interobserver reliability showed excellent agreement between the measurements for C0-C2 lordosis, C2-C7 lordosis and C2-C7 SVA, indicating that the measurements were reliable (Table 2). For T1 slope, the assessment of intra-observer and interobserver reliability showed excellent and good agreement between the measurements (ICC 0.78 and 0.71, respectively).

Postoperative NDI scores ranged from 0 to 39, with a mean of 18.1 ± 11.2. VAS scores ranged from 0 to 8, with a mean of 2.9 ± 2.1. Comparisons between radiographic measurements and HRQOL scores demonstrated a significant positive correlation, between C2-C7 SVA values and NDI scores (r = 0.495, P = 0.005; Figure 2). No significant correlation was identified between radiographic parameters and VAS scores (P > 0.05). Radiographic parameter changes except T1 slope correlated with NDI score changes after surgery (Table 1).

Correlations among the cervical radiographic measurements were examined; this demonstrated significant

TABLE 2. Intra-observer Reproducibility and Interobserver Reliability Using Intraclass Correlation Coefficient

<table>
<thead>
<tr>
<th></th>
<th>Intra-observer</th>
<th>Interobserver</th>
</tr>
</thead>
<tbody>
<tr>
<td>C0-C2 lordosis</td>
<td>0.90</td>
<td>0.88</td>
</tr>
<tr>
<td>C2-C7 lordosis</td>
<td>0.88</td>
<td>0.81</td>
</tr>
<tr>
<td>C2-C7 sagittal vertical axis</td>
<td>0.86</td>
<td>0.82</td>
</tr>
<tr>
<td>T1 slope</td>
<td>0.78</td>
<td>0.71</td>
</tr>
</tbody>
</table>

The intraclass correlation coefficient value less than ±0.40 indicates poor; ±0.40–0.75, fair or good; and ±0.75–1.00, excellent reliability.
Correlations between the C2-C7 SVA measurements and between each C0-C2 lordosis, C2-C7 lordosis, T1 slope, and T1S-CL (Table 3). Significant correlations were found between C2-C7 SVA and C0-C2 lordosis ($r = -0.431$, $P = 0.017$), between C2-C7 SVA and C2-C7 lordosis angles ($r = 0.667$, $P < 0.001$), between C2-C7 SVA and T1S-CL ($r = 0.871$, $P < 0.001$).

The logistic regression model predicted a value of 45 mm for C2-C7 SVA ($\chi^2 = 11.196$, $P = 0.006$) at which the $P$ value for the correlation analyses was most significant. The linear regression predicted a threshold C2-C7 SVA value of 55 mm for an NDI score of 25 ($r^2 = 0.245$, $P = 0.005$; Figure 3). For the correlation tests between C2-C7 SVA and NDI scores, two regression models predicted a threshold C2-C7 SVA value of 50 mm, beyond which correlations were most significant.

T1 slope had a significant positive correlation with both C2-C7 SVA ($r = 0.667$, $P < 0.001$) and T1S-CL ($r = 0.569$, $P = 0.001$). The T1S-CL also correlated positively with C0-C2 lordosis ($r = 0.871$, $P < 0.001$ and $r = 0.470$, $P = 0.009$, respectively). Results of the linear regression analysis indicated that a C2-C7 SVA value of 50 mm corresponded to a T1S-CL value of 28.2°. SVA, sagittal vertical axis; T1S-CL, T1 slope minus C2-C7 lordosis.

The logistic regression model predicted a value of 24° for T1S-CL ($\chi^2 = 13.632$, $P = 0.003$) at which the $P$ value for the correlation analyses was most significant. For the correlation tests between T1S-CL and NDI scores, two

### TABLE 3. Correlations Between Pairs of Radiographic Measures

<table>
<thead>
<tr>
<th>Radiographic Measure</th>
<th>Radiographic Measure</th>
<th>Correlation (Pearson $r$)</th>
<th>$P$ Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>C2-C7 SVA</td>
<td>C0-C2 lordosis</td>
<td>0.431</td>
<td>0.017</td>
</tr>
<tr>
<td>C2-C7 SVA</td>
<td>C2-C7 lordosis</td>
<td>-0.418</td>
<td>0.022</td>
</tr>
<tr>
<td>C2-C7 SVA</td>
<td>T1 slope</td>
<td>0.667</td>
<td>0.000</td>
</tr>
<tr>
<td>C2-C7 SVA</td>
<td>T1S-CL</td>
<td>0.871</td>
<td>0.000</td>
</tr>
<tr>
<td>C2-C7 lordosis</td>
<td>C0-C2 lordosis</td>
<td>-0.578</td>
<td>0.001</td>
</tr>
<tr>
<td>C2-C7 lordosis</td>
<td>T1S-CL</td>
<td>-0.660</td>
<td>0.000</td>
</tr>
<tr>
<td>T1 slope</td>
<td>T1S-CL</td>
<td>0.569</td>
<td>0.001</td>
</tr>
</tbody>
</table>

Significant correlations found between pairs of radiographic parameters using Pearson correlation analysis. SVA indicates sagittal vertical axis; T1S-CL, T1 slope minus C2-C7 lordosis. A $P$ value of <0.05 was considered to indicate statistical significance.
regression models predicted a threshold T1S-CL of 26.1°, beyond which correlations were most significant.

**DISCUSSION**

In this study, we aimed to confirm the relationship between sagittal alignment of the cervical spine and HRQOL scores following multilevel posterior cervical fusion in an Asian population and to explore whether an analogous relationship existed in the cervical spine using the T1S-CL. Similar to a previous study, the severity of disability increased with positive sagittal malalignment following surgical reconstruction in this Asian population at intermediate...

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**Figure 5.** Comparison of the effects of positive sagittal alignment on NDI scores. Upper, a patient with C2-C7 SVA of 17.3 mm and T1S-CL of 12.4° with an NDI score of 13. Lower, a patient with C2-C7 SVA of 47.4 mm and T1S-CL of 30.9° with an NDI score of 39 (severe disability). SVA, sagittal vertical axis; NDI, neck disability index; T1S-CL, T1 slope minus C2-C7 lordosis.
follow-up. Nevertheless, in the current study, C2-C7 SVA exhibited a significant positive correlation with NDI scores; regression models predicted a threshold C2-C7 SVA value of approximately 50 mm, which was predicted as 40 mm in previous research. The difference could be due to ethnic/racial differences. From a statistical viewpoint, our linear regression model was more reliable—in terms of $r^2$ value (0.24 vs. 0.08)—than the previous study.

In the present study, we used the T1S-CL, the cervical analog to PI-LL, to evaluate the association of the cervical analog with alignment parameters of the cervical spine following cervical reconstruction. A significant positive correlation was found between C2-C7 SVA and T1S-CL ($r = 0.871$). Similar to the trend observed in the lumbopelvic spine, the T1S-CL mismatch might significantly impact cervical alignment. The present results indicate that a greater mismatch between T1 slope and C2-C7 lordosis is associated with a greater degree of cervical malalignment and disability, as defined by C2-C7 SVA and NDI scores, respectively. Particularly, a mismatch greater than 26° corresponds to positive cervical sagittal malalignment, defined as C2-C7 SVA greater than 50 mm. In all cases wherein C2-T1 is fused rigidly, there will be a perfect correlation between the misalignment and the C2-C7 SVA. In particular cases, especially with an invisible T1S, it could be a waste of time to measure the T1S-CL mismatch. Although C2-C7 SVA is adequate for predicting cervical malalignment, the T1S-CL could be another clinically relevant parameter for the following reasons: the T1S-CL mismatch may significantly impact disability as well as cervical malalignment, and the analog of “T1S-CL less than 26°” might be used for preoperative or intraoperative surgical planning, similar to PI-LL less than ±9°.

A previous study reported that the T1 slope was influenced by thoracic inlet angle and thoracic kyphosis; that is, the T1 slope is the only parameter that showed a significant correlation with both spinopelvic balance and thoracic inlet alignment. It was suggested that T1 slope was a key parameter influencing cervical spine sagittal balance, as determined by both spinopelvic balance and thoracic inlet alignment. In this study, an increase in T1 slope itself also correlated with an increase in C2-C7 lordosis and C2-C7 SVA, which may indicate a compensatory mechanism to regulate the angle of gaze in the presence of cervical malalignment. Moreover, C2-C7 lordosis and T1S-CL changes correlated with NDI score changes after surgery (Figure 5). It suggested that clinical outcomes including NDI score could be improved by correction of the T1S-CL mismatch; however, a change in T1 slope itself did not demonstrate correlation with NDI changes after surgical reconstruction. This is the first reported study to examine the impact of mismatch between T1 slope and C2-C7 lordosis on cervical malalignment following multilevel cervical fusion in an Asian population. Our findings demonstrate that, similar to the lumbopelvic spine, the severity of cervical malalignment increases with a greater mismatch between T1 slope and C2-C7 lordosis following surgical reconstruction.

Limitations of the study include the small number of enrolled patients and the heterogeneous indications for surgery. General QOL such as SF-36, EQ-5D was not evaluated because of a retrospective study design. Another weakness was the intermediate follow-up period (6 months). The 6-month follow-up period was selected to exclude several long-term risks; however, there is no experimental justification for using the follow-up visit as the ideal time point to perform the analysis. To determine whether pain is due to pseudarthrosis or malalignment, it is first necessary to demonstrate that there is a solid fusion. Then, patients who have a misplaced screw, facet arthrosis, or adjacent level disc herniation must be excluded. Having excluded those and other common causes for pain, one can then determine whether the pain is truly due to malalignment. Furthermore, a longer follow-up is warranted given the length of time for healing of the cervical musculature and possible resolution of the neurologic symptoms. This would have two benefits. First, it would strengthen the results and second, it might reveal some delayed postoperative changes that would influence long-term outcomes such as failure of fusion and failure to maintain alignment. Future study considering the mentioned issues with more than 2-year follow-up could address the real impact of cervical alignment on HRQOL.

**CONCLUSION**

This study shows that disability of the neck increases with progressive cervical sagittal malalignment following cervical reconstructive surgery. Similar to the trend observed in the lumbosacral spine, T1S-CL mismatch may significantly impact cervical alignment. Results indicate that a greater mismatch between T1 slope and C2-C7 lordosis is associated with a greater degree of cervical malalignment and disability, as defined by C2-C7 SVA and NDI scores, respectively. Particularly, a mismatch greater than 26.1° corresponds to positive cervical sagittal malalignment, defined as C2-C7 SVA greater than 50 mm.

**Key Points**

- This study shows that disability of the neck increases with progressive cervical sagittal malalignment following cervical reconstructive surgery.
- C2-C7 lordosis ($P = 0.001$) and T1S-CL ($P = 0.002$) changes correlated with NDI score changes after surgery.
- Similar to the trend observed in the lumbosacral spine, T1S-CL mismatch may significantly impact cervical alignment.
- A mismatch greater than 26.1° corresponds to positive cervical sagittal malalignment, defined as C2-C7 SVA greater than 50 mm.
Acknowledgments
The authors sincerely appreciate Mijin Jung, an artist who drew the illustrations for this article.

References