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

Susan Núñez-Pereira, MD, PhD,¹ Wolfgang Hitzl, PhD, MSC,² Viola Bullmann, MD, PhD,¹ Oliver Meier, MD,³ and Heiko Koller, MD, PD³

¹Spine Surgery Department, St. Franziskus-Hospital, Cologne, Germany; ²Research Office, Biostatistics, Paracelsus Medical University, Salzburg, Austria; and ³German Scoliosis Center Bad Wildungen, Bad Wildungen, Germany

OBJECT Sagittal malalignment of the cervical spine has been associated with worsened postsurgical outcomes. For better operative planning of fusion and alignment restoration, improved knowledge of ideal fusion angles and interdependences between upper and lower cervical spine alignment is needed. Because spinal and spinopelvic parameters might play a role in cervical sagittal alignment, their associations should be studied in depth.

METHODS The authors retrospectively analyzed digital lateral standing cervical radiographs of 145 patients (34 asymptomatic, 74 symptomatic; 37 surgically treated), including full-standing radiographs obtained in 45 of these patients. Sagittal measurements were as follows: C2–7, occiput (Oc)–C2, C1–2 Cobb angles, and C-7 slope (the angle between the horizontal line and the superior endplate of C-7), as well as T4–12 and L1–S1 Cobb angles, sacral slope, pelvic incidence, and C-7 sagittal vertical axis (SVA). A correlation analysis was performed, and linear regression models were developed.

RESULTS Statistical analyses revealed significant correlations between C2–7 and Oc–C2 ($r = -0.4$, $p < 0.01$), Oc–C2 ($r = -0.3$, $p < 0.01$), and C1–2 angle ($r = -0.3$, $p < 0.01$). C-7 slope was significantly correlated with C2–7 ($r = -0.5$, $p < 0.01$) and with Oc–C2 angle ($r = 0.2$, $p = 0.02$). Total cervical (Oc–C7) lordosis was 30.2° and did not differ significantly among asymptomatic, symptomatic, and surgically treated patients. Correlations between C2–7 and Oc–C2 alignment were stronger in asymptomatic patients ($r = -0.5$, $p < 0.01$) and surgically treated patients ($r = -0.5$, $p < 0.01$) than in symptomatic patients ($r = -0.3$, $p = 0.01$), but the between-group difference was not significant ($p > 0.1$). Comparing cervical and spinopelvic alignment revealed a significant correlation between sacral slope and C-7 slope ($r = -0.3$, $p = 0.04$) and C2–7 ($r = 0.4$, $p < 0.01$). The C-7 SVA correlated significantly with the C-7 slope ($r = -0.4$, $p < 0.01$). The interdependences were stronger within the occipitocervical parameters than between the cervical and remaining spinal parameters.

CONCLUSIONS Significant correlations between the upper and lower cervical spine exist, confirming the existence of inherent compensatory mechanisms to maintain overall balance; no significant differences were found among asymptomatic, symptomatic, and surgically treated patients. The C-7 slope is a useful marker of overall sagittal alignment, acting as a link between the occipitocervical and thoracolumbar spine.

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SEVERAL studies have established that failure to reconstruct physiological cervical, thoracolumbar, and lumbosacral alignment before cervical spine surgery can result in significant complications after surgery.^{1,10–12,17,22,24,26} However, thresholds indicating the ideal cervical lordosis for each patient have not yet been estab-

lished. In the cervical spine, malalignment (deviation of the sagittal vertical axis [SVA] intersecting C-2 and C-7) has been linked to worsened clinical outcomes.²³ Among patients with cervical myelopathy, better correction of the lordosis has been linked to greater clinical improvement.² More lordosis has also been associated with better Neck

ABBREVIATIONS Oc = occiput; SVA = sagittal vertical axis.

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Disability Index scores after anterior cervical discectomy and fusion.³

Recent studies stress that in addition to the clinical consequences of cervical malalignment, the geometry of the fusion of the upper cervical spine promotes alignment changes in the subaxial spine.^{8,15} Matsunaga et al.¹⁴ have observed a higher incidence of subaxial cervical malalignment (kyphosis, swan neck deformity, or subluxation) among patients with occipitocervical fusion in an abnormal position. Yoshimoto et al.²⁶ have observed a compensatory decrease of cervical lordosis when C1–2 fusion was in a hyperlordotic posture. Similar compensatory mechanisms have been observed in patients undergoing fusion of the upper cervical region,¹⁸ confirming the interdependence between the craniocervical and subaxial regions.

With the objective of better understanding the interactions between the upper and lower cervical regions, 2 studies of healthy volunteers found negative correlations between the upper cervical spine and the subaxial spine, suggesting use of compensatory mechanisms to maintain balance.^{4,20} Although the number of reports emphasizing the value of lordosis correction is increasing and the existence of compensatory mechanisms between the upper and lower cervical spine have been established, the target magnitude of lordosis restoration in individual patients remains unknown. For accurate surgical planning that specifically addresses lordosis correction, further knowledge of cervical sagittal alignment is paramount.

The cervical spine is not an independent unit because it is connected to the thoracic spine. The overall sagittal balance of the thoracolumbar and lumbosacral spine is expected to influence the cervical spine, which should be the last regulator of the compensatory cascade, which starts at the pelvic region and aims to maintain overall balance.^{13,19} Studies of the treatment of idiopathic scoliosis in adolescents have shown that loss of thoracic kyphosis as a result of surgical coronal plane correction of the scoliosis is associated with a postoperative increase in cervical kyphosis.^{1,6,7} Studies of sagittal alignment include either occipitocervical or thoracolumbopelvic regions, but limited data regarding the connection of these regions are available.¹¹ The SVA is usually measured by using C-7 or C-2 as bony landmarks (C-7 SVA or C-2 SVA), so it is likely that changes in cervical alignment might influence the overall balance, necessitating further studies of the relationship between the occipitocervical spine and the thoracolumbopelvic region. A single study proposed the T-1 sagittal angle as a possible intermediate parameter linking these regions, but the study analyzed correlations with SVA only.⁹

We investigated the strength of physiological interactions between the upper and lower cervical spine and the differences in asymptomatic, symptomatic, and surgically treated (hereafter called postsurgical) patients. We also proposed a new parameter (C-7 slope) and analyzed its performance as a connector between the cervical and thoracolumbar spine. Our objectives were to elucidate the potential influence of thoracolumbosacral alignment on cervical spine alignment. We sought clinically useful prediction models to improve preoperative planning of surgi-

cal cervical alignment reconstruction. To determine the accuracy of the models, we tested them on independent samples.

Methods

Sample Selection

We reviewed a consecutive series of 450 adult patients and their radiographs to select those fulfilling the study criteria. For inclusion in the study, data had to be complete with regard to digital lateral standing cervical radiographs taken in the neutral upright position or full-standing radiographs of the spine including the cervical spine. Patients were consecutively enrolled as they came to our clinic (German Scoliosis Center Bad Wildungen) seeking care for spinal conditions. Patients were excluded if they had undergone any spinal operation during the 6 months before the index radiographs were taken, if the radiographs did not allow measurements of occipitocervical parameters, if C-7 was not identified, or if they had any history of spinal trauma. Enrolled patients were divided into 3 categories according to cervical spine status: asymptomatic, symptomatic, and postsurgical. Asymptomatic patients had had full-standing radiographs taken as part of a diagnostic workup for lumbar pain but did not have any neck pain or cervical spine symptoms. Symptomatic patients included those seeking treatment for cervical spondylosis, radiculopathy, and myeloradiculopathy or after previous cervical surgery. Postsurgical patients included all patients who had experienced uneventful clinical courses after undergoing cervical spine surgery at our clinic. All full-spine radiographs (36-inch cassettes) were taken in a standardized manner by the same team and with all patients in the same position; patients were asked to stand erect but comfortably, select a horizontal visual axis, and hold their arms at the level of the clavicles. To test the generalizability of the obtained models, we assessed an additional independent test sample of 20 consecutively selected patients.

Measurements

All measurements were performed digitally by using an Infinitt PACS (picture archiving communication system) (Infinitt Healthcare). Lordosis was indicated by a negative value, and kyphosis was indicated by a positive value.

The reference lines and angle measurements were defined (Fig. 1). The occipitocervical association was evaluated in the following 2 ways: 1) between the McGregor line and the line drawn below C-2 connecting the anterior tip of the endplate to the inferior tip of the C-2 lamina and 2) between the McRae line and the line drawn below C-2. The McGregor line is drawn from the posterior aspect of the hard palate to the most caudal point on the midline of the occipital curve. The McRae line is drawn from the basion to the opisthion.¹⁶ The C1–2 angle was defined as the angle subtended by a line drawn parallel to the inferior aspect of C-1 and the line below C-2 as defined above. C2–7 lordosis was measured by using both the Cobb and Harrison tangent methods. The C2–7 Cobb angle was subtended by a line parallel to the inferior endplate of C-2 and

FIG. 1. Cervical spine measurements and osseous landmarks described in the *Methods* section. Copyright Susan Núñez-Pereira. Published with permission. Figure is available in color online only.

a line parallel to the inferior endplate of C-7. The Harrison angle of C2–7 was the angle subtended by a line drawn parallel to the posterior border of C-2 and a line drawn parallel to the posterior border of C-7.⁵ The C-7 slope was defined as the angle subtended by a line parallel to the superior endplate of C-7 and a horizontal reference line.

For patients for whom full-standing radiographs were available, the following additional measurements were performed. Thoracic kyphosis (T4–12) was the angle subtended by a line parallel to the superior endplate of T-4 and a line parallel to the inferior endplate of T-12. Lumbar lordosis (L1–S1) was the angle subtended by a line parallel to the superior endplate of L-1 and a line parallel to the superior endplate of S-1. Sacral slope was the angle subtended by a line parallel to the superior endplate of S-1 and a horizontal reference line. Pelvic incidence was the angle subtended by a bisector line perpendicular to the superior endplate of S-1 and a line connecting the center of the S-1 endplate and the middle of the hip axis. C-7 SVA was the horizontal distance between the posterosuperior corner of the sacrum at S-1 and a vertical plumb line centered in the middle of the C-7 vertebral body.

Statistical Analyses

Data were carefully analyzed for possible outliers and for the assumptions of the models (normality by using probability plots and in doubtful cases by using the Kolmogorov-Smirnov test). Independent Student t-tests were used to compare means, and Fisher exact tests were used to analyze 2×2 cross-tabulation tables. Correlation analyses were performed to examine associations among the selected variables. Linear regression models were set up,

and 95% confidence intervals for means were computed. To test the generalizability of the models, we prospectively analyzed an additional independent test sample of 20 consecutively selected patients and applied the prediction equations to the patients' cervical spine radiographs and measurements, respectively. All reported tests were 2 sided, and p values less than 0.05 were considered statistically significant. All statistical analyses were performed by use of STATISTICA 10 (StatSoft) and SPSS (SPSS Statistics for Windows, version 19.0).

Results

The study included 145 patients (100 with cervical radiographs and 45 with full-standing radiographs). The mean $\pm$ SD patient age was 53.6 ± 13.4 years; age did not differ significantly among patients in the 3 groups ($p = 0.7$). A total of 99 patients (68%) were women and 46 (32%) were men; 34 patients (23.4%) were asymptomatic, 74 (51%) were symptomatic, and 37 (25.5%) were postsurgical.

Tables 1 and 2 summarize the sex- and diagnostic group-stratified means and standard deviations of the performed measurements. Differences associated with patient sex were only observed in the C2–7 Harrison and Cobb angles and in C-7 slope measurements. Age correlated significantly with C-7 slope ($r = -0.2$, $p = 0.02$) and C-7 SVA ($r = 0.4$, $p = 0.01$) only.

The main correlations among the measured parameters are summarized in Table 3. Statistically significant correlations between occipitocervical and subaxial parameters were observed between the occiput (Oc)–C2 McGregor line and C2–7 Cobb angle ($r = -0.4$, $p < 0.01$), Oc–C2

TABLE 1. Radiographic measurements for all patients*

Variable	Asymptomatic	Postsurgical	Symptomatic	p Value
C2–7 Cobb (°)	-15.8 ± 13.2	-21.2 ± 13.2	-18.9 ± 12.2	0.2
Oc–C2 McGregor (°)	-12.7 ± 6.9	-11.9 ± 7.9	-10.4 ± 9.7	0.1
C1–2 Cobb (°)	-20.8 ± 7.3	-17.6 ± 4.9	-17.8 ± 6.5	0.05
Oc–C7 (°)	-28.7 ± 12.0	-32.3 ± 11.3	-29.8 ± 13.1	0.5
C-7 slope (°)	-23.4 ± 11.7	-29.3 ± 8.9	-22.3 ± 11.7	0.01
TK T4–12 (°)	34.3 ± 17.1	35.2 ± 9.8	31.3 ± 9.4	0.9
LL L1–S1 (°)	-46.2 ± 15.2	-47.5 ± 10.7	-51.5 ± 8.1	0.7
Sacral slope (°)	30.8 ± 14.3	33.9 ± 7.4	41.7 ± 7.7	0.2
Pelvic incidence (°)	54.3 ± 13.6	58.1 ± 13.3	68.7 ± 17.9	0.2
Pelvic tilt (°)	24.0 ± 10.9	26.9 ± 10.6	28.4 ± 12.9	0.7
C-7 SVA (mm)	30.4 ± 39.9	41.6 ± 43.4	19.08 ± 24.4	0.5

Cobb = Cobb angle; LL = lumbar lordosis; McGregor = McGregor line; TK = thoracic kyphosis.

* Boldface indicates statistical significance. Values are expressed as mean ± SD.

McGregor line and C1–2 ($r = 0.5$, $p < 0.01$), and C1–2 and C2–7 ($r = -0.3$, $p < 0.01$). The C-7 slope correlated significantly with Oc–C2 ($r = 0.2$, $p = 0.02$) and C2–7 Cobb angle ($r = 0.5$, $p < 0.01$). Correlations were stronger in asymptomatic and postsurgical patients than in symptomatic patients (Table 4), between Oc–C2 and C2–7 (asymptomatic, $r = -0.5$, $p = 0.01$; postsurgical, $r = -0.5$, $p < 0.01$; symptomatic, $r = -0.3$, $p = 0.01$) and between C2–7 and C-7 slope (asymptomatic, $r = 0.6$, $p < 0.01$; postsurgical, $r = 0.5$, $p < 0.01$; symptomatic, $r = 0.4$, $p < 0.01$); however, the differences between the groups did not reach statistical significance ($p > 0.1$).

When cervical parameters were compared with spinopelvic parameters, the strongest correlations were observed between lumbar lordosis and C2–7 Cobb angle ($r = 0.4$, $p = 0.01$) and between spinal slope and C-7 slope ($r =$

0.3 , $p = 0.02$). The C-7 SVA correlated significantly with C2–7 Harrison angle ($r = 0.3$, $p = 0.02$) and C-7 slope ($r = -0.4$, $p < 0.01$).

A multivariate linear regression analysis revealed that a useful model could be established for predicting cranio-cervical and subaxial cervical alignment. The equations for predicting the alignment of C1–2, C2–7 Cobb angle, and C-7 slope were as follows (Figs. 2–4):

$$C1-2 = -12.74 + 0.6 \times (Oc-C2) \quad (r = 0.55, p < 0.00001)$$

$$C2-7 \text{ Cobb} = -28.3 - 0.8 \times (Oc-C2) \quad (r = -0.45, p < 0.000001)$$

$$C-7 \text{ slope} = -16.5 + 0.44 \times (C2-7 \text{ Cobb}) \quad (r = 0.53, p < 0.000001)$$

To test the generalizability of the models, we prospectively assessed an independent test sample of 20 consecutively selected patients (3 asymptomatic, 11 symptomatic, 6 postsurgical; mean ± SD patient age 55.1 ± 12.1 years) and applied the prediction equations to the patients' cervical spine radiographs and measurements, respectively. No significant differences were found between the values measured from the radiographs and those predicted by using the equations. The measured and predicted values and the mean differences are summarized in Table 5.

Discussion

Understanding the normal ranges of compensatory mechanisms is paramount for successful reconstruction of the cervical region. Our findings confirm the presence of compensatory mechanisms linking the occipitocervical and subaxial spine, not only in asymptomatic patients but also in symptomatic and postsurgical patients. The identification of stable compensatory mechanisms can be valuable for the appropriate reconstruction of alignment, particularly in patients who have undergone previous surgeries and who have cervical malalignment, as well as in patients who have undergone craniocervical and C1–2 fusion surgery. The investigated parameter described here

TABLE 2. Radiographic measurements stratified according to patient sex*

Variable	Male	Female	p Value for Differences
C2–7 Harrison (°)	19.9 ± 13.2	14.6 ± 12.1	0.02
C2–7 Cobb (°)	-22.5 ± 13.8	-17.1 ± 11.9	0.02
Oc–C2 McGregor (°)	-10.0 ± 10.8	-11.9 ± 7.4	0.2
C1–2 Cobb (°)	-17.9 ± 5.8	-18.7 ± 6.7	0.5
Oc–C1 (°)	9.0 ± 7.9	8.9 ± 7.5	0.9
Oc–C7 (°)	-31.6 ± 14.6	-29.6 ± 11.3	0.4
C-7 slope (°)	-27.6 ± 12.6	-22.9 ± 10.5	0.02
TK T4–12 (°)	34.4 ± 7.8	33.9 ± 16.4	0.9
LL L1–S1 (°)	-49.3 ± 13.5	-46.5 ± 13.9	0.5
Sacral slope (°)	37.5 ± 9.1	31.5 ± 13.5	0.1
Pelvic incidence (°)	57.0 ± 15.0	57.5 ± 14.9	0.9
Pelvic tilt (°)	20.9 ± 9.8	27.8 ± 10.8	0.1
C-7 SVA (mm)	34.9 ± 54.7	30.2 ± 33.2	0.7

Harrison = Harrison angle.

*Boldface indicates statistical significance. All values are expressed as mean ± SD.

TABLE 3. Correlations obtained among measured parameters*

	C2–7 Cobb	C2–7 Harrison	Oc–C2 McGregor	C1–2 Cobb	C-7 Slope	TK T4–12	LL L1–S1	Sacral Slope	Pelvic Incidence	C-7 SVA (mm)
C2–7 Cobb	1	r = -0.8 p < 0.01	r = -0.4 p < 0.01	r = -0.3 p < 0.01	r = 0.5 p < 0.01	r = -0.05 p = 0.7	r = -0.1 p = 0.5	r = 0.2 p = 0.2	r = 0.1 p = 0.6	r = -0.05 p = 0.8
C2–7 Harrison		1	r = -0.3 p < 0.01	r = 0.2 p = 0.2	r = 0.5 p < 0.01	r = -0.1 p = 0.4	r = 0.4 p = 0.01	r = -0.2 p = 0.1	r = 0.04 p = 0.8	r = 0.3 p = 0.02
Oc–C2 McGregor			1	r = 0.5 p < 0.01	r = 0.2 p = 0.02	r = -0.01 p = 0.9	r = -0.2 p = 0.3	r = 0.3 p = 0.1	r = 0.02 p = 0.9	r = -0.2 p = 0.1
C1–2 Cobb				1	r = 0.02 p = 0.8	r = 0.3 p = 0.1	r = -0.1 p = 0.3	r = 0.1 p = 0.6	r = 0.5 p = 0.8	r = -0.08 p = 0.6
C-7 slope					1	r = -0.12 p = 0.2	r = -0.2 p = 0.3	r = -0.3 p = 0.02	r = -0.02 p = 0.9	r = -0.4 p < 0.01
TK T4–12						1	r = -0.30 p = 0.04	r = -0.2 p = 0.3	r = -0.01 p = 0.9	r = -0.03 p = 0.9
LL L1–S1							1	r = -0.7 p < 0.01	r = -0.5 p = 0.02	r = 0.6 p < 0.01
Sacral slope								1	r = 0.6 p < 0.01	r = -0.4 p = 0.01
Pelvic incidence									1	r = 0.05 p = 0.8
C-7 SVA (mm)										1

* Boldface indicates statistical significance.

(C-7 slope) is correlated with cervical, spinal, and spino-pelvic parameters. C-7 slope could be useful as an indicator of global sagittal thoracolumbar balance for patients undergoing cervical reconstructive surgery. However, studies with larger samples should explore the associations among these parameters in more depth, thus enabling the inclusion of global balance into the planning of cervical reconstructive surgery.

Normal Values, Sex, and Age Differences

The measured values vary widely. Guo et al.⁴ reported mean values for Oc–C2 and C2–7 Cobb angle as -14.9° and -22.5° for male patients and -16.3° and -12.7° for female patients, respectively. In our sample of patients, Oc–C2 and C2–7 Cobb were slightly higher. Small differences are associated with the use of slightly different measurement techniques regarding the C-2 reference. When both angles were used to obtain the total amount of lordosis (Oc–C7), our results were -32.5° for male patients and -28.0° for female patients; these results are similar to those of Guo et al., who obtained -31.2° for male and -29.0° for female patients. In summary, a normal mean for total cervical lordosis is approximately 30° . Some variations exist between patients of each sex. Our results stressed that in asymptomatic patients, Oc–C2 lordosis will provide approximately 40% of the total amount of lordosis. The Guo et al. study also revealed slight differences with regard to sex and age in the occipitocervical alignment of healthy volunteers.⁴ In our sample, age correlated only with C-7 SVA and C-7 slope, and differences between sexes were observed for C2–7 Cobb angle and C-7 slope only. However, the limited sample sized did not allow for further comparisons among age groups. Compensatory cervical mechanisms

might change with age, and differences have already been observed in previous studies of healthy volunteers.⁴ Larger studies are needed to further explore this issue.

Occipitocervical Measurements

Measurements of the occipitocervical angle obtained by using the McGregor line showed better correlations than did those obtained by using the McRae line; thus, we recommend use of the McGregor line in future studies. Findings might be associated with the observation that the McGregor line shows the best interobserver and intra-observer correlations when compared with measurements performed by using the Chamberlain or McRae lines.²¹ The C2–7 Cobb angle correlated better with the rest of the parameters than did the Harrison posterior tangent method.⁵ Hence, the former measurement is our choice for further comparisons.

Cervical Interdependences

Our finding of a negative correlation between C2–7 and Oc–C2 alignment in asymptomatic, symptomatic,

TABLE 4. Correlations obtained for occipitocervical parameters among the 3 groups

Parameter	Correlation		
	Asymptomatic	Symptomatic	Postsurgical
Oc–C2 w/ C2–7	r = -0.5, p = 0.01	r = -0.3, p = 0.01	r = -0.5, p < 0.01
C2–7 w/ C-7 slope	r = 0.6, p < 0.01	r = 0.4, p < 0.01	r = 0.5, p < 0.01

FIG. 2. Regression analysis and model equation for calculation of the C1–2 angle based on Oc–C2. Figure is available in color online only.

and postsurgical patients confirms a compensatory effect acting between the occipitocervical and subaxial cervical spine segments to maintain the overall sagittal balance. Previously, this effect was demonstrated for healthy persons only.⁴ The negative correlation between the occipitocervical and subaxial spine could also be observed between C1–2 and C2–7, but the correlation coefficient was slightly smaller than that of the interdependence of Oc–C2 and C2–7. Guo et al.⁴ performed both measurements in asymptomatic healthy volunteers and found that C1–2 alignment correlated better with that of C2–7 than that of Oc–C2, but the differences they observed were small. Their study sample consisted of Chinese patients, whereas ours consisted of Caucasian patients; these different populations might explain some of the slight differences in the angulations and measurements. Recent reports have shown that spinopelvic parameters do differ between Chinese and Caucasian populations,²⁵ so it is pos-

FIG. 3. Regression analysis and model equation for calculation of the C-7 slope based on the C2–7 Cobb angle. Figure is available in color online only.

FIG. 4. Regression analysis and model equation for calculation of the C2–7 Cobb angle based on Oc–C2. Figure is available in color online only.

sible that occipitocervical alignment could differ further among persons of different races. Future studies should assess this issue.

Most studies performed previously have used asymptomatic volunteers,^{4,20} populations with specific diseases (e.g., rheumatoid arthritis¹⁴ or congenital atlantoaxial dislocations¹⁸), or only postsurgical patients.²⁶ In patients with those pathologies, alignment probably differs from that in patients with cervical spondylosis and degenerative disc diseases. In our study, the interdependences of cervical geometry between the different regions were weaker in symptomatic patients, as shown by the statistical strength of the correlations, than in asymptomatic and postsurgical patients. It is possible that pain promotes alterations in cervical alignment (e.g., segmental alignment changes, including pathologic flexion to increase spinal canal volume in patients with cervical stenosis). However, significant correlations in the symptomatic group indicate that cervical interdependences and compensatory mechanisms continued to be effective, although limited, for spinal segments between the Oc and T-1.

When the models in an independent sample obtained by analyzing our sample of 145 patients were tested, accuracy for calculating the predicted values for cervical alignment parameters was high. The observed differences between the predicted and obtained values were minimal ($< 2.5^\circ$ for all parameters) and not significant. Application of the prediction models to an additional, independent sample of patients confirmed the utility of the proposed models. The models enable calculation of optimum fusion angles for each patient on the basis of the given spinal parameters and might support surgical planning.

C-7 Slope and Cervicospinopelvic Interdependences

The C-7 slope is a novel parameter for the assessment of global spinal alignment and the association between cervical and spinopelvic parameters. The value of this parameter was significantly higher for male patients and postsurgical patients. Knott et al.⁹ proposed using the T-1

TABLE 5. Measured values compared with the predicted values obtained by using the equations provided by the model in an independent test sample

Measured vs Predicted	Measured Value (mean $\pm$ SD)	Predicted Value (mean $\pm$ SD)	Mean Paired Difference	SD	p Value
C2–7 Cobb/predicted C2–7 (after Oc–C2)	-20.3 $\pm$ 11.5	-18.1 $\pm$ 4.7	-2.2	10.9	0.4
C-7 slope/predicted C-7 slope (after C2–7 Cobb)	-23.6 $\pm$ 10.2	-25.4 $\pm$ 5.1	1.8	8	0.3
C1–2/predicted C1–2 (after Oc–C2)	-18.1 $\pm$ 5.3	-16.2 $\pm$ 9.5	-1.9	10.1	0.4

tilt to predict the overall sagittal balance of the spine and found a significant correlation ($r = 0.65$) with the SVA measured at C-2. However, their study was focused on the SVA at C-2, and they did not investigate potential interrelations between the T-1 tilt and the rest of the spinopelvic parameters. The T-1 tilt is not always easy to measure because the shoulders usually obscure the upper thoracic spine; the superior endplate of C-7 is easier to determine. An additional advantage of using C-7 slope is that it can be easily measured on isolated cervical radiographs. C-7 slope correlated well with cervical alignment at C2–7 and with upper cervical alignment at Oc–C2. The more C-7 is tilted anteriorly, the more the upper levels compensate into a lordotic posture. The C-7 slope correlated significantly with not only C2–7 and Oc–C2 but also with spinal slope and C-7 SVA. The results revealed that C-7 slope might be a useful indicator of global sagittal balance. If C-7 slope is altered on cervical radiographs, full-length radiographs should be obtained to rule out sagittal imbalance, which could potentially alter the outcome of cervical spine correction surgery, particularly for patients undergoing multi-level cervical fusion and fusions crossing the cervicothoracic junction.

In the absence of larger studies of cervical sagittal balance, our study adds new data and insight into the interdependences of the cervical spine and between the cervical and remaining thoracolumbar spine that contribute to a better understanding of cervical sagittal balance. The interdependences between different cervical states were stable, and statistical models revealed good prediction accuracy.

Limitations

Because our sample size was limited, thereby preventing us from arriving at more conclusive results, further research could investigate a larger number of patients in each group. Further studies could also improve the accuracy of predictions (e.g., cervical alignment based on thoracolumbar shape and balance). Of additional interest would be studying postsurgical patients separately from asymptomatic and symptomatic patients.

Conclusions

Significant correlations exist between the upper and lower cervical spine, confirming the existence of inherent compensatory mechanisms used to maintain overall balance. Significant differences between asymptomatic, symptomatic, and postsurgical patients were not observed. The cervical interdependences seem to be stably main-

tained throughout the continuum between asymptomatic persons and patients with cervical spine disorders.

The proposed statistical models were accurate when tested with an independent test sample; thus, they seem to be useful for alignment correction planning. Further research must prove their value for clinical decision making.

The C-7 slope is a useful marker of overall sagittal alignment, acting as a link between the occipitocervical and thoracolumbar spine.

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Author Contributions

Conception and design: Koller. Acquisition of data: Núñez-Pereira. Analysis and interpretation of data: Núñez-Pereira. Drafting the article: Núñez-Pereira. Critically revising the article: Núñez-Pereira, Bullmann, Koller. Reviewed submitted version of manuscript: Núñez-Pereira. Approved the final version of the manuscript on behalf of all authors: Núñez-Pereira. Statistical analysis: Hitzl. Administrative/technical/material support: Meier. Study supervision: Koller.

Correspondence

Susana Núñez-Pereira, Spine Surgery Department, St. Franziskus-Hospital, Schönsteinstr. 63, 50825 Cologne, Germany. email: snunezpereira@gmail.com.