

Jun Mizutani, MD*‡
 Russell Strom, MD‡
 Kuniyoshi Abumi, MD[§]
 Kenji Endo, MD[¶]
 Ken Ishii, MD^{||}#
 Mitsuru Yagi, MD^{||}**
 Bobby Tay, MD^{††}
 Vedat Deviren, MD^{††}
 Christopher Ames, MD[‡]

*Department of Rehabilitation Medicine and Department of Orthopaedic Surgery, Nagoya City University Graduate School of Medical Sciences, Nagoya, Japan; ‡Department of Neurological Surgery, University of California San Francisco, California, USA; §Department of Orthopaedic Surgery, Sapporo Orthopaedic Hospital, Sapporo, Japan; ¶Department of Orthopaedic Surgery, Tokyo Medical University, Tokyo, Japan; ||Department of Orthopaedic Surgery, Keio University School of Medicine, Tokyo, Japan; #Department of Orthopaedic Surgery, School of Medicine, International University of Health and Welfare (IUHW), Tochigi, Chiba, Japan; **Department of Orthopaedic Surgery, National Hospital Organization Murayama Medical Center, Tokyo, Japan; ††Department of Orthopaedic Surgery, University of California San Francisco, California, USA

Correspondence:

Jun Mizutani, MD,
 Department of Orthopaedic Surgery and
 Rehabilitation Medicine,
 Nagoya City University,
 Graduate School of Medical Sciences,
 1-Kawsumi, Mizuho-cho,
 Mizuho-Ku, Nagoya, 467-8601, Japan.
 E-mail: mjun.macl@mac.com

Received, June 11, 2017.

Accepted, March 21, 2018.

Published Online, April 28, 2018.

© Congress of Neurological Surgeons
 2018.

This is an Open Access article distributed under the terms of the Creative Commons Attribution-NonCommercial-NoDerivs licence (<http://creativecommons.org/licenses/by-nc-nd/4.0/>), which permits non-commercial reproduction and distribution of the work, in any medium, provided the original work is not altered or transformed in any way, and that the work is properly cited. For commercial re-use, please contact journals.permissions@oup.com

How Cervical Reconstruction Surgery Affects Global Spinal Alignment

BACKGROUND: There have been no reports describing how cervical reconstruction surgery affects global spinal alignment (GSA).

OBJECTIVE: To elucidate the effects of cervical reconstruction for GSA through a retrospective multicenter study.

METHODS: Seventy-eight patients who underwent cervical reconstruction surgery for cervical kyphosis were divided into a Head-balanced group (n = 42) and a Trunk-balanced group (n = 36) according to the values of the C7 plumb line (PL). We also divided the patients into a cervical sagittal balanced group (CSB group, n = 18) and a cervical sagittal imbalanced group (CSI group, n = 60) based on the C2 PL-C7 PL distance. Various sagittal Cobb angles and the sagittal vertical axes were measured before and after surgery.

RESULTS: Cervical alignment was improved to achieve occiput-trunk concordance (the distance between the center of gravity [COG] PL, which is considered the virtual gravity line of the entire body, and C7 PL < 30 mm) despite the location of COG PL and C7PL. A subsequent significant change in thoracolumbar alignment was observed in Head-balanced and CSI groups. However, no such significant change was observed in Trunk-balanced and CSB groups. We observed 1 case of transient and 1 case of residual neurological worsening.

CONCLUSION: The primary goal of cervical reconstruction surgery is to achieve occiput-trunk concordance. Once it is achieved, subsequent thoracolumbar alignment changes occur as needed to harmonize GSA. Cervical reconstruction can restore both cervical deformity and GSA. However, surgeons must consider the risks and benefits in such challenging cases.

KEY WORDS: Cervical kyphotic deformity, Cervical spine reconstruction, Sagittal vertical axis, Spinal deformity, Occiput-trunk concordance, Global spinal alignment

Neurosurgery 84:898–907, 2019

DOI:10.1093/neuros/nyy141

www.neurosurgery-online.com

Cervical kyphotic deformity causes significant impairment due to the inability to gaze horizontally and problems with mastication and swallowing.¹ Despite these impairments, cervical deformity has received little attention in literature.¹ Previous reports that address remedies to cervical deformity have not assessed its effects on global spinal alignment.²⁻⁸ Instead, investigations into

remedies for cervical kyphotic deformity have predominantly focused on local factors, such as the cervical kyphotic angle.²⁻⁸ Therefore, the association between cervical kyphosis and global spinal alignment has not been fully elucidated. Tang et al⁹ recently reported that a greater cervical sagittal imbalance was associated with poorer health-related quality of life. Their report evaluated the cervical spine for parameters such as the C2-C7 sagittal vertical axis (SVA) and the cervical kyphotic angle; however, the report did not evaluate global spinal alignment.

There is increasing recognition that complex global interactions occur between the sagittal curves of the entire spine and pelvis.¹⁰⁻¹⁴ Although several studies have reported changes in cervical alignment after thoracolumbar reconstruction surgery,^{1,15-17} there have been no

ABBREVIATIONS: AP, anterior and posterior; AS, ankylosing spondylitis; COG, center of gravity of the head; CSB, cervical sagittal balanced; CSI, cervical sagittal imbalanced; GSA, global spinal alignment; HRQOL, health-related quality of life; IRB, institutional review board; LL, lumbar lordosis; OT, occiput-trunk; PI, pelvic incidence; PL, plumb line; SVA, sagittal vertical axis

reports investigating how cervical reconstruction surgery affects global spinal alignment. Accordingly, this study investigated radiographic reciprocal changes in thoracolumbar alignment after cervical reconstruction surgery for cervical kyphotic deformity.

METHODS

Following institutional review board (IRB) approval and a waiver of informed consent from the IRB, the data of patients who attended each of the 5 participating institutions between 2012 and 2014 were retrospectively reviewed.

Inclusion and Exclusion Criteria

Our study targeted patients with primary cervical or cervicothoracic junctional kyphosis whose symptoms originated from there. Consecutive patients diagnosed with cervical kyphosis, chin-on-chest deformity, cervical sagittal imbalance, or dropped-head syndrome who were recommended cervical reconstruction surgery were included. Patients diagnosed with cervical myelopathy with local kyphosis or entire cervical kyphosis who were recommended surgery were also included. The following exclusion criteria were applied: patients who did not undergo surgery due to their circumstances; those for whom a standing full-spine radiograph was unavailable or inadequate; those with a thoracolumbar coronal or sagittal deformity of $>30^\circ$; those with prior thoracolumbar-sacral fusions extending to the pelvis or starting above the 10th thoracic vertebra; and/or if there was thoracolumbar fusion, including the thoracolumbar junction and/or lumbar-sacral junction. Patients with a kyphotic apex that was in the thoracic spine, in the thoracolumbar junction, in the lumbar spine, or those who had a total kyphotic spine were also excluded. In addition, patients with thoracolumbar rigidity, such as ankylosing spondylitis (AS), were also excluded.

Radiographic Definitions and Measurements

Standing full-spine lateral digital radiographs and cervical spine radiographs were analyzed. Measurements of sagittal Cobb angles and SVAs were performed based on the methods described by Tang et al⁹ and our previous report.¹⁸

Pelvic incidence (PI) and pelvic tilt were evaluated as spinopelvic parameters. The T1 slope (angle between the superior endplate of T1 and the horizontal line), Cobb_{T4-12} (the sagittal Cobb angle between T4 and T12), Cobb_{L1-5} (the sagittal Cobb angle between L1 and L5), and Cobb_{CL} (Cobb_{CL} the angle between the endplate of C2 and inferior endplate of C7 if patients did not have distal junctional kyphosis due to previous surgery) were also measured. For patients with cervical lordosis due to a prior cervical fusion but also with distal junctional kyphosis, Cobb_{CL} was defined as the sagittal Cobb angle between the C2 endplate and the inferior endplate of the most superior vertebra that caused distal junctional kyphosis (Figure 1, dotted line), following our previous report.¹⁸

For SVAs, we measured the center of gravity (COG) of the head (SVA_{COG}; distance between the COG plumb line (PL) and superior posterior corner of the sacrum), SVA_{C2} (distance between the C2 PL and superior posterior corner of the sacrum), SVA_{C7} (distance between the C7 PL and superior posterior corner of the sacrum), SVA_{COG-C7} (distance between the COG PL and C7), and SVA_{C2-C7} (distance between the C2 PL and C7).

Measurements based on sagittal Cobb angles were assigned positive and negative values for kyphosis and lordosis, respectively.¹⁹ Thus, in

this study PI-lumbar lordosis (LL) was defined as the value of PI minus absolute value of LL.

As outlined by Yagi et al,²⁰ occiput-trunk (OT) concordance was defined as $SVA_{COG-C7} \leq 30$ mm and OT discordance was defined as $SVA_{COG-C7} > 30$ mm. Cervical sagittal imbalance was defined as $SVA_{C2-C7} > 40$ mm, as described by Tang et al.⁹

Enrolled Patients

Based on data from 5 institutions, 142 consecutive patients met the inclusion criteria. In total, 27 patients did not undergo surgery due to the patients' personal circumstances, and 38 patients were excluded because the radiographs obtained were inadequate for evaluating the parameters in this study or because postsurgical, full standing spinal radiographs were not obtained. There were no patients with a coronal deformity $>30^\circ$. None of the patients who underwent thoracolumbar fusion surgery met the exclusion criteria. Additionally, there were no totally fused spine patients, such as AS, or cervical deformity patients with thoracic apex or lumbar apex.

Ultimately, 78 patients were enrolled in this study. Among them, 25 underwent anterior reconstruction and 53 underwent either posterior reconstruction with instrumentation, including 3-column osteotomy, or a combination of anterior and posterior (AP) reconstruction surgery. We also assessed the etiology of each case. Among 25 patients who underwent anterior surgery, 9 patients developed entire cervical kyphosis with multi-level degenerative disc lesion, 8 patients developed myelopathy with local kyphosis, 6 patients developed adjacent level disorders because of prior fixation surgery, and 2 patients developed postlaminectomy kyphosis. In addition, among 53 patients who underwent posterior or combined both AP surgeries, 5 patients exhibited dropped head syndrome, 25 patients exhibited distal junctional kyphosis, 20 patients exhibited post laminectomy kyphosis, and 3 patients suffered instrumentation failure.

The average Cobb_{CL} in patients who underwent posterior or AP surgery was 33.7° (range, -2° - 88°). In patients who underwent anterior reconstruction, the average Cobb_{CL} was 19.1° (range, 3° - 51°), indicating that the Cobb_{CL} in patients who received anterior reconstruction surgery was relatively mild. However, all patients who underwent anterior reconstruction surgery had local kyphosis in the middle and/or lower cervical segments with a local kyphosis of 20.6° (range, 6° - 51°).

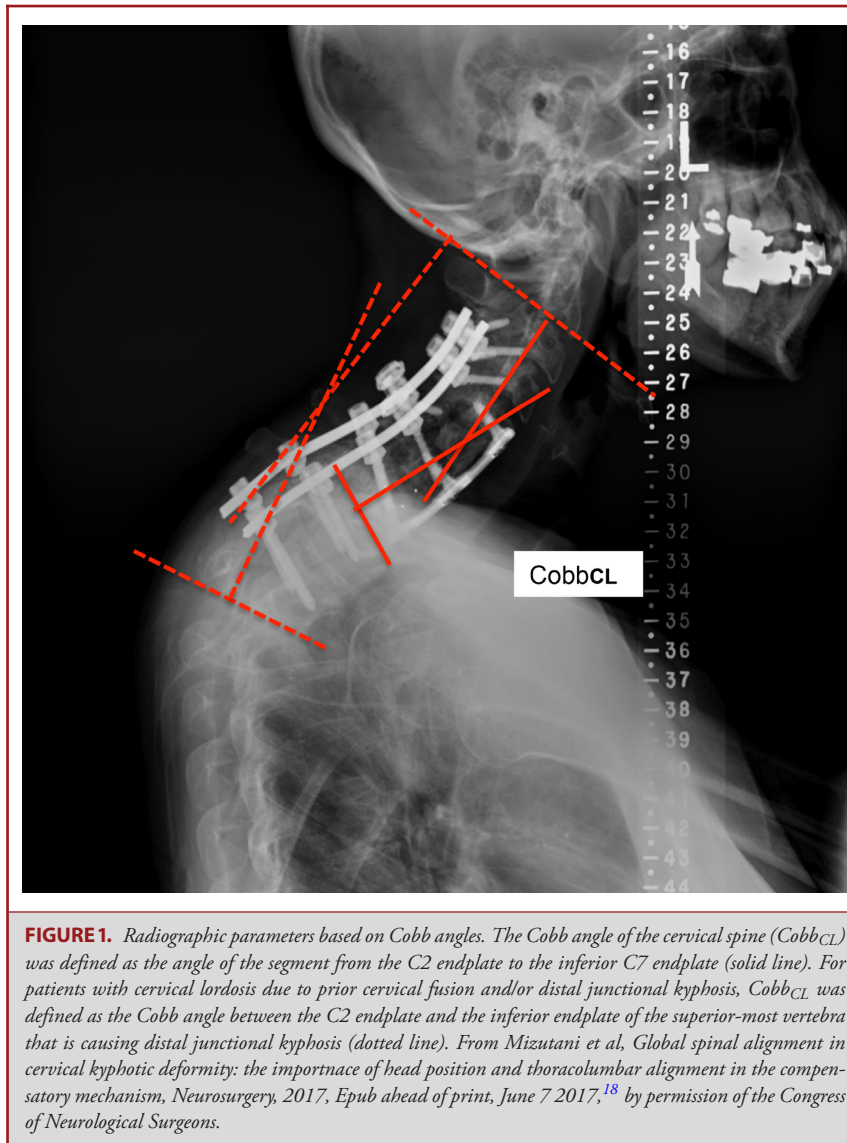
Comparison

Head-Balanced and Trunk-Balanced Groups

We previously reported that cervical kyphotic patients display 2 distinct patterns of global spinal balance according to the value of SVA_{C7},¹⁸ which we termed Head-balanced and Trunk-balanced. Head-balanced patients are those with a negative SVA_{C7} value, a larger LL than PI (indicating hyper LL) and a low T1 slope. Trunk-balanced patients are those with a positive SVA_{C7} value, who are at the upper limit of a harmonized PI-LL, and have a relatively normal T1 slope value. Based on these measurements, patients were divided into the Trunk-balanced and Head-balanced groups based on the presurgical C7 PL.

Cervical Sagittal Imbalanced Group and Cervical Sagittal Balanced Group

In line with Tang's reports,⁹ we also compared the parameters between the cervical sagittal imbalanced (CSI) group and cervical sagittal balanced (CSB) groups. Patients with an SVAC2-C7 of more than 40 mm were classified into the CSI group ($n = 60$), and the remaining patients with an SVAC2-C7 of less than 40 mm were classified into the CSB group ($n = 18$).



Statistical Analysis

All statistical analyses were performed using JMP version 10 (SAS Institute Inc, Cary, North Carolina). Effects of cervical reconstruction on thoracolumbar alignment and various SVAs before and after surgery were determined for each subgroup using paired t -tests. An unpaired t -test was used to compare the pre- and postoperative status of each group. A P value of $<.05$ was considered statistically significant.

RESULTS

Patient Demographics of the 2 Subgroups

Head-Balanced Group and Trunk-Balanced Group

Table 1 shows baseline patient characteristics of the Head-balanced and Trunk-balanced groups. In the Trunk-balanced

group, the C7 PL was on the femoral head and the COG PL was shifted anteriorly. In contrast, the Head-balanced group had a COG PL that was on the femoral head but a C7 PL that was markedly shifted posteriorly. Thoracolumbar sagittal curvatures and PI-LL were significantly different between the groups (Table 1).

CSI Group and CSB Group

Table 2 shows baselines for the CSI and CSB groups. The T1 slope and $Cobb_{TK}$ were smaller in the CSB group than the CSI group (Table 2). Although both groups indicated cervical kyphosis, the CSI group had an OT discordance and cervical sagittal imbalance.

TABLE 1. Baseline Characteristics and Various Parameters in the Head-Balanced and Trunk-Balanced Groups

		Head-balanced	Trunk-balanced	P value	Entire cohort
Age and number	Age at surgery (yr)	62.2 ± 13.2	64.6 ± 13.6	NS	63.3 ± 13.4
	Patient number (% women)	42 (64.2)	36 (55.6)	NS	78 (60.2)
	PI	56.2 ± 13.6	55.7 ± 14.4	NS	56.0 ± 13.9
	PT	19.6 ± 10.7	22.8 ± 14.0	NS	21.1 ± 12.4
Cervical parameters	Cobb _{CL}	29.3 ± 22.2	25.6 ± 19.8	NS	27.2 ± 21.1
	SVA _{COG-C7}	80.8 ± 44.9	87.8 ± 52.5	NS	83.8 ± 48.1
	SVA _{C2-C7}	63.2 ± 32.9	59.5 ± 31.1	NS	61.6 ± 32.0
	SVA _{COG}	32.1 ± 44.2	129.6 ± 78.2	<.0001	74.4 ± 77.8
	SVA _{C2}	12.1 ± 40.9	104.8 ± 61.5	<.0001	54.8 ± 69.1
Thoracolumbar parameters	SVA _{C7}	-51.2 ± 32.1	45.2 ± 41.2	<.0001	74.4 ± 77.8
	T1 slope	15.5 ± 16.9	29.1 ± 22.3	.0066	20.8 ± 20.3
	Cobb _{T4-12}	29.9 ± 17.6	38.8 ± 16.5	.008	33.5 ± 17.8
	Cobb _{L1-5}	-56.8 ± 16.3	-44.4 ± 18.1	.0011	-51.0 ± 18.2
	PI-LL	-1.3 ± 15.4	11.4 ± 16.9	.0005	4.6 ± 17.3

PI: pelvic incidence.

PT: pelvic tilt.

SVA: sagittal vertical axis.

COG: center of the gravity of the head.

NS: not significant.

TABLE 2. Baseline Characteristics and Various Parameters in the Cervical Sagittally Imbalanced and Cervical Sagittally Balanced Groups

		CSI group	CSB group	P value	Entire cohort
Age, number, and pelvic parameters	Age at surgery (yr)	65.4 ± 12.7	57.3 ± 15.2	.0301	63.3 ± 13.4
	Patient number (% women)	60 (58.3)	18 (66.7)	NS	78 (60.2)
	PI	58.6 ± 13.1	55.6 ± 14.9	NS	56.0 ± 13.9
	PT	19.6 ± 11.5	19.7 ± 12.7	NS	21.1 ± 12.4
Cervical parameters	Cobb _{CL}	23.3 ± 22.5	20.2 ± 14.6	NS	27.2 ± 21.1
	SVA _{COG-C7}	91.4 ± 42.7	32.7 ± 19.4	<.0001	83.8 ± 48.1
	SVA _{C2-C7}	67.7 ± 27.0	23.2 ± 16.5	<.0001	61.6 ± 32.0
	SVA _{COG}	66.0 ± 79.0	40.0 ± 39.5	.0086	74.4 ± 77.8
	SVA _{C2}	42.2 ± 72.8	30.4 ± 33.5	.0206	54.8 ± 69.1
Thoracolumbar parameters	SVA _{C7}	-25.3 ± 65.6	7.2 ± 32.3	NS	74.4 ± 77.8
	T1 slope	23.0 ± 19.8	17.2 ± 16.8	.0179	20.8 ± 20.3
	Cobb _{T4-12}	36.2 ± 17.7	24.1 ± 13.0	.0016	33.5 ± 17.8
	Cobb _{L1-5}	-52.1 ± 14.9	-50.1 ± 27.0	NS	-51.0 ± 18.2
	PI-LL	4.9 ± 15.0	2.8 ± 22.6	NS	4.6 ± 17.3

CSI: cervical sagittal imbalance.

CSB: cervical sagittal balance.

PI: pelvic incidence.

PT: pelvic tilt.

SVA: sagittal vertical axis.

COG: center of the gravity of the head.

NS: not significant.

Pre- and Postoperative Radiographic Changes Observed in Each Subgroup

Head-Balanced Group and Trunk-Balanced Group

Following surgery, both groups almost achieved OT concordance and cervical sagittal balance. The Trunk-balanced group

exhibited a significant posterior shifting of COG PL, representing head position. The C7 PL in the Head-balanced group was significantly moved anterior; however, no significant change in SVA_{C7} was observed in the Trunk-balanced group. These findings are summarized in Table 3.

TABLE 3. Pre- and Postoperative Changes in Various Parameters in Each Group

		Head-balanced group			Trunk-balanced group		
		Pre	Post	Significance	Pre	Post	Significance
Cervical parameters	SVA _{C2}	12.1 ± 40.9	30.9 ± 32.1	.0011	104.8 ± 61.5	85.8 ± 62.3	.0234
	SVA _{COG}	32.1 ± 44.2	40.0 ± 33.5	.0361	129.6 ± 78.2	78.9 ± 52.6	.0052
	SVA _{C7}	-51.2 ± 32.1	-3.47 ± 30.2	<.0001	45.2 ± 41.2	44.0 ± 54.0	NS
	SVA _{C2-C7}	63.2 ± 32.9	35.3 ± 21.6	.0038	59.5 ± 31.1	38.2 ± 20.3	.0086
	SVA _{COG-C7}	80.8 ± 44.9	39.6 ± 24.0	.0015	87.8 ± 52.5	44.6 ± 27.9	.0019
	Cobb _{CL}	29.3 ± 22.2	-2.69 ± 10.0	<.0001	25.6 ± 19.8	0.64 ± 15.2	<.0001
Thoracolumbar parameters	T1 slope	15.5 ± 16.9	27.3 ± 8.8	<.0001	29.1 ± 22.3	33.5 ± 10.9	NS
	Cobb _{T4-12}	29.9 ± 17.6	33.9 ± 14.5	.0005	38.8 ± 16.5	41.0 ± 15.0	NS
	Cobb _{L1-5}	-56.8 ± 16.3	-51.2 ± 14.0	.0028	-44.4 ± 18.1	-45.1 ± 16.0	NS
	PI-LL	-1.3 ± 15.4	5.7 ± 15.2	.0003	11.4 ± 16.9	11.1 ± 17.1	NS

SVA: sagittal vertical axis.

COG: center of gravity of the head.

PI: pelvic incidence.

NS: not significant.

While no significant changes in thoracolumbar sagittal Cobb or PI-LL were observed in the Trunk-balanced group (Table 3), the Head-balanced group exhibited significant postsurgical changes in the Cobb_{T4-12}, Cobb_{L1-5}, T1 slope, and PI-LL.

Figure 2A shows a correlation between preoperative SVA_{C7} and preoperative PI-LL. The Head-balanced group showed statistically significant correlations, indicating the more that the C7 PL was shifted posteriorly, the greater preoperative hyper lordosis. The Trunk-balanced group showed no such correlation.

Figure 2B shows a correlation between preoperative PI-LL and delta LL. The delta LL was defined as the value of postoperative LL minus that before surgery. The Head-balanced group showed statistically significant correlations, indicating the greater preoperative hyper LL, the greater the delta LL in patients. The Trunk-balanced group showed no such correlation. Figure 2C shows a correlation between preoperative LL and delta LL. Delta LL was normally distributed (Figure 2D) and the mean degree of delta LL was 3.12° and the standard deviation was 10.5°.

CSI Group and CSB Group

Table 4 shows pre- and postoperative changes in the CSI and CSB groups. The values of SVA_{C2-C7} and SVA_{COG-C7} in the CSI group were significantly decreased, indicating achievement of cervical sagittal balance and of almost OT concordance. Regarding thoracolumbar parameters, T1 slope and Cobb_{T4-12} were increased and Cobb_{L1-5} was decreased with statistical significance in the CSI group, while in the CSB group, the significant change was limited only in the T1 slope and Cobb_{T4-12}.

Patients' Symptoms and Complications

Fifty-three of 78 patients had preoperative difficulty in gazing horizontally, obtained comfortable horizontal gaze, and were satisfied with their surgery. All 53 patients who underwent

posterior or combined anterior/posterior surgery felt noticeable improvement with preoperative muscle stiffness in the trapezius or cervical para-spinal muscles following surgery, although at least 8 patients complained of newly acquired axial symptoms due to posterior surgery.

Two patients experienced neurological deterioration; however, such outcome was transient in 1 patient, who recovered within a few months. The other patient developed permanent and modest clumsiness. These 2 patients underwent pedicle subtraction osteotomy of the C7 vertebra.

Representative Cases

Figure 3 presents a representative Head-balanced patient. Figure 4 shows a representative Trunk-balanced patient.

Case 1

A 76-yr-old woman with postlaminectomy kyphosis. Preoperatively, she complained of difficulty in maintaining a horizontal gaze, neck pain, stiffness of the trapezius muscle, and slight low back pain. Combined cervical AP reconstruction surgery was performed. Cervical reconstruction surgery approximated OT concordance by anterior movement of the C7 PL. Her neck pain disappeared and her lower back pain was reduced following surgery. She was also able to gaze horizontally after surgery.

Case 2

A representative of a female Trunk-balanced patient, aged 78. She had undergone cervical posterior fixation and developed subjacent kyphosis. No significant changes in thoracolumbar alignment were observed between pre- and postsurgery, although she acquired OT concordance and achieved superior cervical sagittal balance by posterior movement of the COG PL.

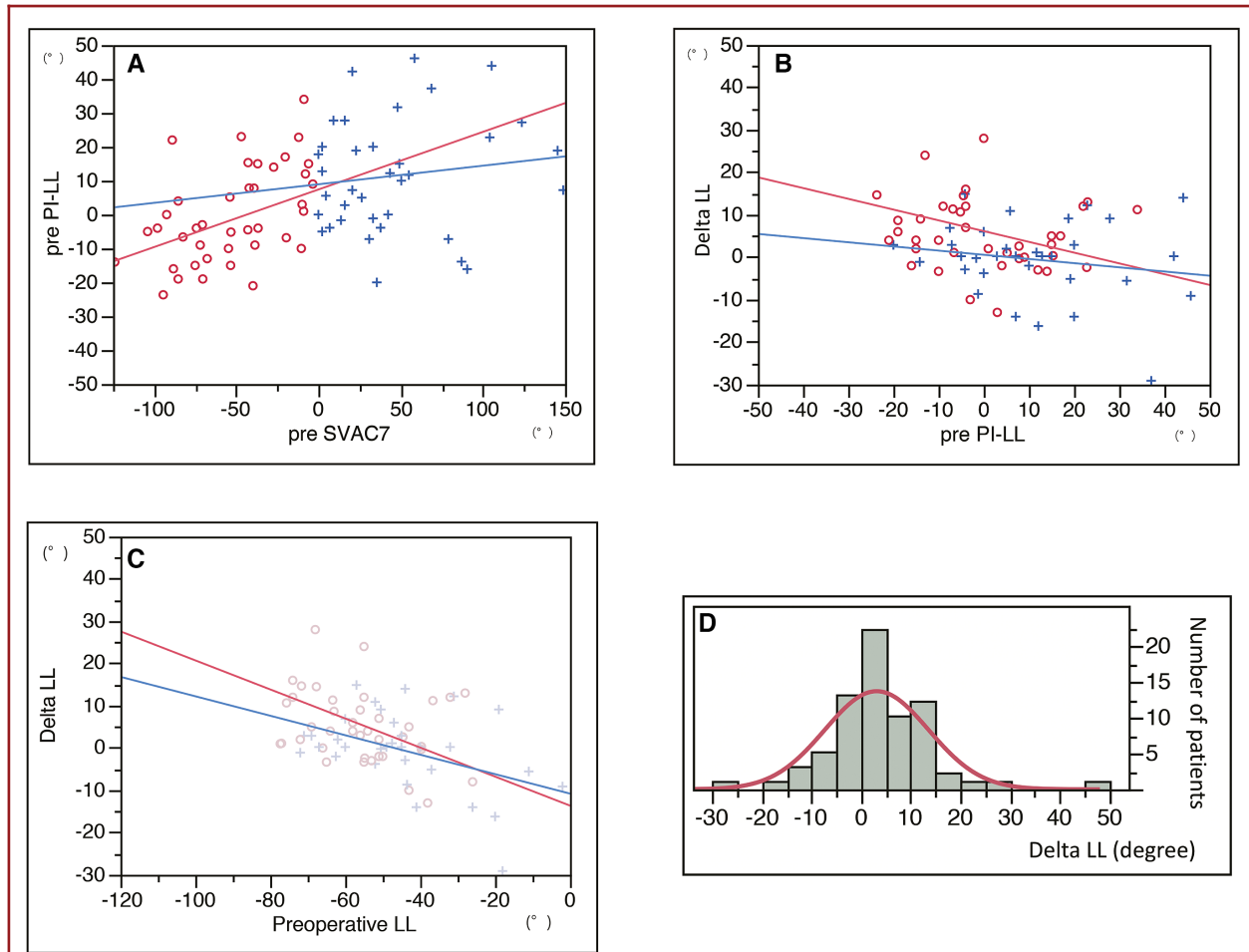


FIGURE 2. Each patient is represented by a “red circle and red line” (Head-balanced group) or a “blue cross and blue line” (Trunk-balanced group). There is a significant correlation between **A**, preoperative SVA_{C7} and preoperative PI-LL; **B**, preoperative PI-LL and delta LL; and **C**, preoperative LL and delta LL in the Head-balanced group, while there was no correlation in Trunk-balanced group (**A-C**). **D**, Furthermore, delta LL was normally distributed. SVA_{C7} : distance between the C7 PL and superior posterior corner of the sacrum; PI: pelvic incidence; LL: sagittal Cobb angle between L1 and L5; Delta LL: value of postoperative LL minus that of preoperative LL. **A**, Correlation between preoperative SVA_{C7} and preoperative PI-LL. Preoperative PI-LL = $7.4131859 + 0.1699047 \times \text{pre-SVAC7}$. $R^2 = 0.127$ ($P = .0223$) in the Head-balanced group. Preoperative PI-LL = $8.9424208 + 0.0548045 \times \text{pre-SVAC7}$. $R^2 = 0.0117$ ($P = .4397$) in the Trunk-balanced group. **B**, Correlation between preoperative PI-LL and delta LL. Delta LL = $6.142821 - 0.2534723 \times \text{pre-PI-LL}$. $R^2 = 0.1$ ($P = .0154$) in the Head-balanced group. Delta LL = $0.5620386 - 0.0983961 \times \text{pre-PI-LL}$. $R^2 = 0.03$ ($P = .3297$) in the Trunk-balanced group. **C**, Correlation between preoperative LL and delta LL. Delta LL = $-13.63657 - 0.3435697 \times \text{pre-LL}$. $R^2 = 0.31$ ($P = .0003$) in the Head-balanced group. Delta LL = $-10.79379 - 0.230259 \times \text{pre-LL}$. $R^2 = 0.19$ ($P = .0123$) in the Trunk-balanced group. **D**, Distribution of delta LL. Delta LL was normally distributed. Mean degree of delta LL was 3.12° and the standard deviation was 10.5° .

DISCUSSION

Significance of Acquiring OT Concordance and Movement of PLs

There has been increasing interest in the concept of the gravity line.²²⁻²⁶ Sugrue et al²⁵ emphasized that the goal of a truly balanced spine is to maintain the position of the head over the femoral head. They also stated that each of the individual regions of the spine must articulate and align with each other to

appropriately position the head. Thus, true global sagittal balance should consider the position of the head in relation to the spine and pelvis; notably, in contrast with this, the C7 PL has been used as a gold standard to assess global spinal alignment.^{20,26} Using the C7 PL is typically concordant with the virtual gravity line, which is expressed as the COG PL.²⁰ The distance between the COG PL and C7 PL is typically <30 mm in healthy populations, so-called OT-concordance.²⁰ Patients are usually able to put their COG and C7 PLs onto the pelvis simultaneously to

TABLE 4. Pre- and Postoperative Changes in Various Parameters in Each Group

		CSI group			CSB group		
		Pre	Post	Significance	Pre	Post	Significance
Cervical parameters	SVA _{C2}	42.2 ± 72.8	46.0 ± 57.1	NS	30.4 ± 33.5	48.4 ± 42.4	NS
	SVA _{COG}	66.0 ± 79.0	51.4 ± 25.6	NS	40.0 ± 39.5	55.5 ± 38.2	NS
	SVA _{C7}	-25.3 ± 65.6	9.7 ± 51.5	.0002	7.2 ± 32.3	17.7 ± 34.2	NS
	SVA _{C2-C7}	67.7 ± 27.0	36.3 ± 20.9	<.0001	23.2 ± 16.5	30.8 ± 20.1	NS
	SVA _{COG-C7}	91.4 ± 42.7	41.8 ± 25.6	<.0001	32.7 ± 19.4	37.8 ± 26.7	NS
	Cobb _{CL}	23.3 ± 22.5	-1.2 ± 11.5	<.0001	20.2 ± 14.6	-1.5 ± 16.9	.0011
Thoracolumbar parameters	T1 slope	23.0 ± 19.8	31.0 ± 9.9	.0013	17.2 ± 16.8	26.4 ± 11.2	.0142
	Cobb _{T4-12}	36.2 ± 17.7	39.2 ± 15.1	.00125	20.1 ± 13.0	30.6 ± 11.2	.043
	Cobb _{L1-5}	-52.1 ± 14.9	-48.4 ± 14.3	.0063	-50.1 ± 27.0	-48.9 ± 18.0	NS
	PI-LL	4.9 ± 15.0	9.0 ± 16.0	.0016	2.8 ± 22.6	4.8 ± 15.2	NS

CSI: cervical sagittal imbalance.

CSB: cervical sagittal balance.

SVA: sagittal vertical axis.

COG: center of gravity of the head.

PI: pelvic incidence.

NS: not significant.

maintain global spinal alignment. Another report proposed the concept of cervical sagittal imbalance. Tang et al⁹ reported that SVAC2-C7 values greater than 40 mm are associated with worse patient health-related quality of life (HRQOL). Yoshida et al²⁷ mentioned that ambiguity of using COG PL and also mentioned utility of using C2 PL. Thus, both concepts of OT concordance and cervical sagittal imbalance indicate relationships between the position of the head and global spinal balance despite the fact that the C2 PL does not completely indicate the position of the head.

Sugrue et al²⁵ noted that the use of the COG PL and craniocervical balance play particularly important roles in cervicothoracic and occipitocervical deformity; however, he also noted that no studies have addressed the impact of the position of the head in relation to the sacrum. The current study showed that postoperative SVA_{COG-C7} was 41.5 ± 25.5 mm and that postoperative SVA_{C2-C7} was 36.5 ± 20.9 mm. All patients who complained of difficulty in gazing horizontally became comfortable gazing horizontally, and stiffness of the trapezius muscle or cervical paraspinal muscle were improved. Ultimately, the goal of cervical reconstruction surgery would be to achieve OT concordance and cervical sagittal balance.

Regarding PL movement, this study showed that each PL (the COG PL and C7 PL) moved onto the femoral head as needed to achieve OT concordance despite the lines' previous locations. The COG PL moved posteriorly in the Trunk-balanced group, and the C7 PL moved anteriorly in the Head-balanced group. When cervical sagittal balance was maintained prior to surgery, drastic movements of the COG PL and C7 PL were not observed. There were no significant changes in the CSB group, while a significant anterior movement of the C7 PL was observed in the CSI group.

To improve the relationship between the position of the head and global spinal balance, the goal of cervical reconstruction surgery would be to achieve OT concordance or cervical sagittal balance.

Subsequent Changes in the T1 Slope and Thoracolumbar Alignment

Complex global interactions are increasingly being recognized to occur among the sagittal curves of the entire spine and pelvis.¹⁰⁻¹⁴ Several studies have reported changes in cervical alignment after thoracolumbar reconstruction surgery^{1,15-17}; however, no reports have investigated how cervical reconstruction surgery affects global spinal alignment. To the best of our knowledge, this is the first report to show a thoracolumbar alignment change after cervical reconstruction surgery.

This study revealed that subsequent thoracolumbar alignment change occurred as needed. In the Head-balanced group, the value of the T1 slope and Cobb_{T4-12} increased and Cobb_{L1-5} decreased. In the Trunk-balanced group, there were no significant changes in thoracolumbar alignment. These results indicated that preoperative thoracolumbar compensatory alignment improved and decompensated and achieved better global spinal alignment following surgery in the Head-balanced group; however, only posterior movement of the COG PL achieved better global spinal alignment in the Trunk-balanced group.

When comparing the CSB and CSI groups, significant changes in T1 slope, Cobb_{T4-12}, and Cobb_{L1-5} were observed in the CSI group. However, no significant alignment change in the lumbar segment was observed in the CSB group. These results indicate that severe cervical kyphotic deformity affects thoracolumbar decompensation down to the lumbar spine; in contrast,

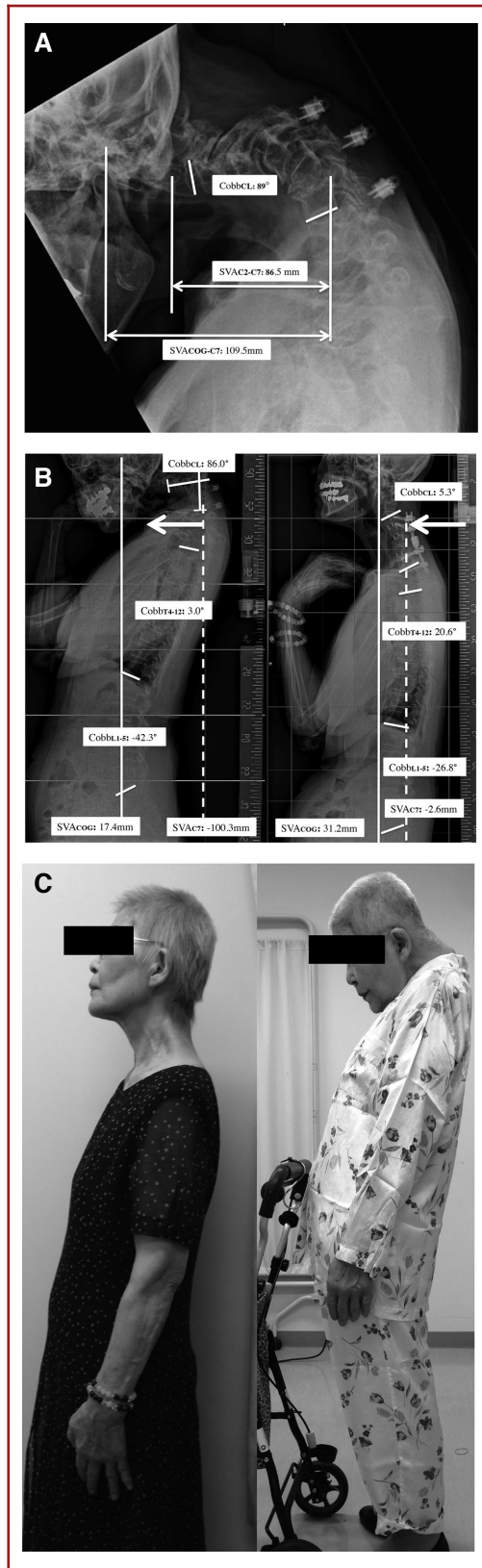


FIGURE 3. Case 1. Representative Head-balanced type patient. **A.** Preoperative plain lateral cervical radiograph. Severe postlaminectomy kyphosis is apparent. Cobb_{CL} is 87°, SVACOG-C7 is 163.5 mm, and SVAC_{C2-C7} is 91.3 mm, all of which indicate severe OT discordance and cervical sagittal imbalance. **B.** Changes in global spinal parameters between surgeries. The C7 PL moved anteriorly (from -100.3 to -2.6 mm) to approximate OT concordance and cervical sagittal balance (SVACOG-C7 became 46.1 mm and SVAC_{C2-C7} became 37.5 from 91.3 mm). Consequently, thoracolumbar reciprocal alignment changes occurred in the T1 slope from 2° to 27°, LL from 42.3° to 26.8°, and TK from 3.0° to 20.6°. **C.** Changes in the appearance of the patient between surgeries. The patient was able to gaze horizontally after surgery. Stiffness around her trapezius muscle was relieved and the lower back pain disappeared. Reprinted from Mizutani J.²¹ Used by permission of Kanehara & Co., Tokyo, Japan.

the preoperative compensatory mechanism was limited to the thoracic segment in mild cervical kyphosis; thus, the decompensation following surgery was also limited only in thoracic segment. Cervical reconstruction surgery would affect thoracolumbar decompensation as preoperative severity of cervical deformity.

Limitations

The most important limitation of this study is that it did not make associations with HRQOL. Therefore, this research should be interpreted from a critical perspective. We confirmed that all patients who complained of a difficulty maintaining a horizontal gaze acquired a comfortable horizontal gaze after surgery. However, severe complications, including death, have been reported in previous studies²⁻⁸ of complicated cervical reconstruction surgery. Fortunately, we did not encounter such catastrophic complications; however, we did observe neurological aggravation in 2 patients. In addition, among the patients who were excluded because of the lack of standing full spine X-rays, 2 patients complained of neurological worsening. Surgeons must be aware that neurological aggravation could possibly occur despite radiographic success following cervical reconstruction surgery.

We could not provide information on related HRQOL because this was a multicenter retrospective analysis that was conducted internationally. Additionally, HRQOL was slightly beyond the scope of our primary research question, which was whether thoracolumbar radiographic change occurs following cervical reconstruction surgery in patients with primary cervical deformity whose apex was cervical or cervicothoracic junction. This limitation was recognized at the planning stage. Thus, future prospective studies involving HRQOL and clinical symptoms are needed to further establish surgical strategies to treat cervical kyphotic deformity, although we believe that the results of this study provide important evidence in the field of spinal alignment.

Secondly, the current study does not include all of the etiological factors for cervical kyphotic deformity. Patients who

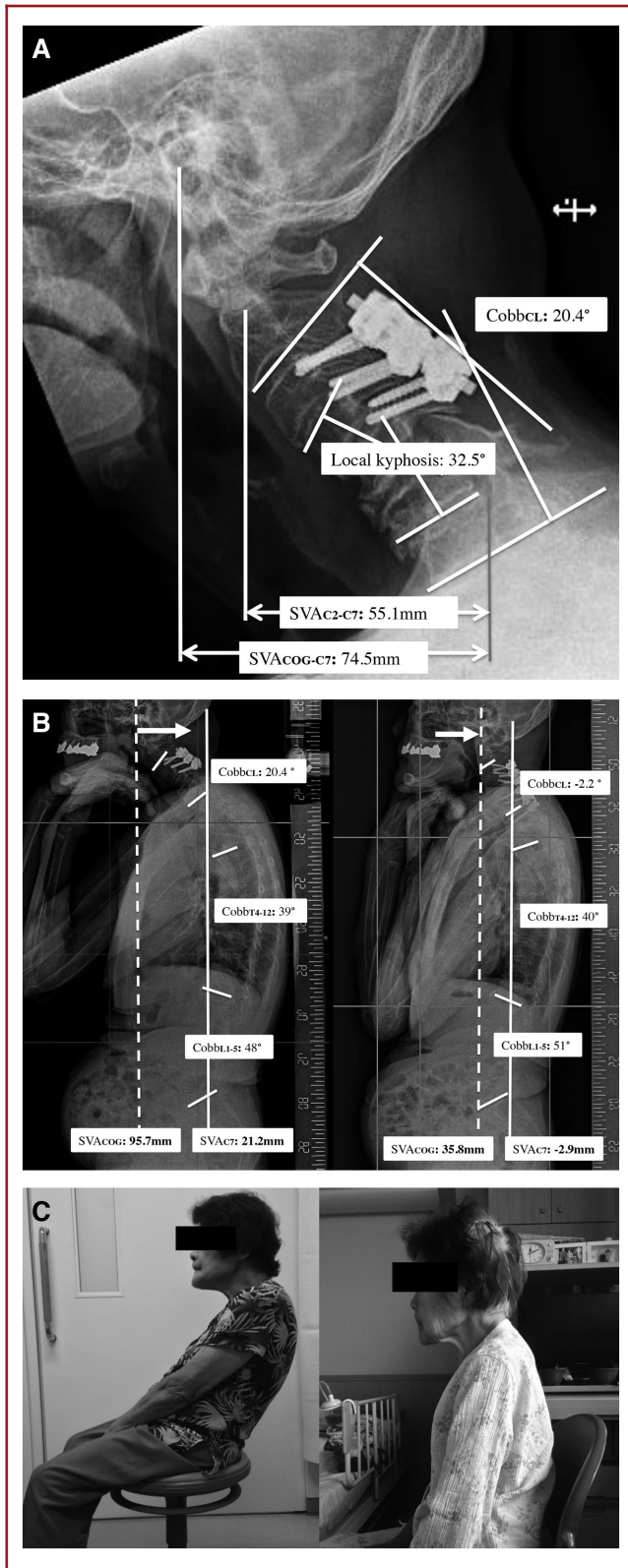


FIGURE 4. Case 2. Representative trunk-balanced type patient. **A**, Preoperative plain cervical lateral radiograph. The patient underwent C3-5 fusion previously and developed a subjacent local kyphosis of 32.5°. Cobb_{CL} was from 38° to -3°, SVA_{COG-C7} from 93.0 to 47 mm, and SVA_{C2-C7} from 60.0 to 36 mm, indicating OT discordance and cervical sagittal imbalance. **B**, Changes in cervical and global spinal parameters between surgeries. SVA_{COG} moved posteriorly (from 93 to 42 mm), while SVA_{C7} remained from 15 to 0 mm. Therefore, the value of the SVA_{C7} is -83.5 mm. T1 slope, LL, and PI are 18.0°, -49.7°, and 66.5°, respectively. Due to the large SVA_{COG-C7} (109.5 mm), this patient could not align the COG PL and C7 PL by cervical extension. The driving force to adjust the COG PL on the femoral head instead requires a posterior shift of the C7 PL. Consequently, the larger LL follows this posterior shifting of the C7 PL and decreases the T1 slope. **C**, Changes in the appearance of the patient between surgeries. The patient was able to gaze horizontally after surgery, whereas before surgery she was obliged to lean backward to achieve a horizontal gaze. Her stiffness around the trapezius muscle was also relieved. SVA, sagittal vertical axis; COG, center of gravity of the head; OT, occiput-trunk; PL, pelvic incidence; LL, lumbar lordosis.

had both thoracolumbar and cervical kyphotic deformity were excluded to elucidate our research question clearly. These patients could have had cervical kyphosis due to the decompensated stage of adult thoracolumbar deformity, as demonstrated by Yoshida et al²⁷ and Yagi et al,²⁰ and as observed in patients with Parkinson's disease.^{20,27} The thoracolumbar reciprocal change would be similar between the Trunk-balanced group in this study and the cervical deformity patients with thoracolumbar rigidity whose SVA is approximately 40 mm since they are balanced below the trunk. Additionally, in this cohort, there were no totally fused spine patients with both cervical kyphosis and thoracolumbar deformity sometimes seen in AS patients. There were no patients who underwent prior thoracolumbar long-fusion with severe cervical kyphosis. For cervical deformity patients with both thoracolumbar rigidity and coexisting large SVA, the thoracolumbar compensatory mechanism is different and may warrant classification into another subgroup. For these patients, thoracolumbar reconstruction might be required simultaneously or in advance based on recent advances in the management of adult deformity. However, this subgroup is the remaining unsolved issue in the management of cervical reconstruction surgery.

Finally, our results were not related to HRQOL and thus cannot be generalized the surgical strategy; therefore, we can only speculate that primary cervical deformity patients without coexisting issues in the thoracolumbar spine could undergo kyphotic correction surgery to adjust SVA_{COG-C7} to within 40 mm rather than to acquire cervical lordosis. We assume that for patients with coexisting cervical deformity and thoracolumbar rigidity with large SVA, thoracolumbar reconstruction may be required simultaneously or in advance as mentioned above; however, appropriate surgical strategy for these patients is unsettled. Relatedly, it is also important to investigate HRQOL for the lumbar spine and/or low back pain because there were cases in which low back pain has improved even after cervical reconstruction surgery. Further prospective studies are required to resolve these unsettled issues.

CONCLUSION

This is the first report describing how cervical reconstruction surgery affects radiographic thoracolumbar alignment changes. We evaluated postoperative alignment changes in 4 different situations. Postoperative alignment changes were found to be dependent on the severity of cervical deformity and preoperative thoracolumbar compensatory alignment. The goal of cervical reconstruction surgery would be to achieve OT concordance and/or cervical sagittal balance; subsequent thoracolumbar alignment change then occurs as needed. Mild cervical deformity only affected subjacent thoracic decompensation; however, severe deformity affected the lumbar and thoracic segments. Cervical reconstruction surgery can restore both cervical sagittal alignment and global spinal harmony. However, in such challenging cases, neurological complications are likely to occur and surgeons must be mindful of the risks and benefits of such difficult cervical reconstruction surgeries. To better understand surgical strategy and obtain new evidence in this field, further prospective studies that include HRQOLs are needed.

Disclosures

Part of this work was supported by the Grant-in-Aid Japan Society for the Promotion of Science (JSPS KAKENHI; grant numbers 24592206 and 15K10414). The authors have no personal, financial, or institutional interest in any of the drugs, materials, or devices described in this article.

REFERENCES

- Lamartina C, Berjano P. Classification of sagittal imbalance based on spinal alignment and compensatory mechanisms. *Eur Spine J*. 2014;23(6):1177-1189.
- Abumi K, Kaneda K, Shono Y, Fujiya M. One-stage posterior decompression and reconstruction of the cervical spine by using pedicle screw fixation systems. *J Neurosurg*. 1999;90(1):19-26.
- Abumi K, Shono Y, Ito M, Taneichi H, Kotani Y, Kaneda K. Complications of pedicle screw fixation in reconstructive surgery of the cervical spine. *Spine*. 2000;25(8):962-969.
- Etame AB, Wang AC, Than KD, La Marca F, Park P. Outcomes after surgery for cervical spine deformity: review of the literature. *Neurosurg Focus*. 2010;28(3):E14.
- Grosso MJ, Hwang R, Krishnaney AA, Mroz TE, Benzel EC, Steinmetz MP. Complications and outcomes for surgical approaches to cervical kyphosis. *J Spinal Disord Tech*. 2015; 28(7):E385-E393.
- Han K, Lu C, Li J, et al. Surgical treatment of cervical kyphosis. *Eur Spine J*. 2011;20(4):523-536.
- Hann S, Chalouhi N, Madineni R, et al. An algorithmic strategy for selecting a surgical approach in cervical deformity correction. *Neurosurg Focus*. 2014;36(5):E5.
- Mummaneni PV, Dhall SS, Rodts GE, Haid RW. Circumferential fusion for cervical kyphotic deformity. *J Neurosurg Spine*. 2008;9(6):515-521.
- Tang JA, Scheer JK, Smith JS, et al. The impact of standing regional cervical sagittal alignment on outcomes in posterior cervical fusion surgery. *Neurosurgery*. 2012;71(3):662-669; discussion 669.
- Boulay C, Tardieu C, Hecquet J, et al. Sagittal alignment of spine and pelvis regulated by pelvic incidence: standard values and prediction of lordosis. *Eur Spine J*. 2006;15(4):415-422.
- Ha Y, Schwab F, Lafage V, et al. Reciprocal changes in cervical spine alignment after corrective thoracolumbar deformity surgery. *Eur Spine J*. 2014;23(3):552-559.
- Hilibrand AS, Tannenbaum DA, Graziano GP, Loder RT, Hensinger RN. The sagittal alignment of the cervical spine in adolescent idiopathic scoliosis. *J Pediatr Orthop*. 1995;15(5):627-632.
- Lafage V, Schwab F, Vira S, et al. Does vertebral level of pedicle subtraction osteotomy correlate with degree of spinopelvic parameter correction? *J Neurosurg Spine*. 2011;14(2):184-191.
- Lafage V, Schwab F, Vira S, Patel A, Ungar B, Farcy JP. Spino-pelvic parameters after surgery can be predicted: a preliminary formula and validation of standing alignment. *Spine*. 2011;36(13):1037-1045.
- Cacho-Rodrigues P, Campana M, Obeid I, Vital JM, Gille O. Sagittal correction and reciprocal changes after thoracic pedicle subtraction osteotomy. *Spine*. 2016;41(13):E791-E797.
- Obeid I, Boniello A, Boissiere L, et al. Cervical spine alignment following lumbar pedicle subtraction osteotomy for sagittal imbalance. *Eur Spine J*. 2015;24(6):1191-1198.
- Smith JS, Shaffrey CI, Lafage V, et al. Spontaneous improvement of cervical alignment after correction of global sagittal balance following pedicle subtraction osteotomy. *J Neurosurg Spine*. 2012;17(4):300-307.
- Mizutani J, Verma K, Endo K, et al. Global spinal alignment in cervical kyphotic deformity: the importance of head position and thoracolumbar alignment in the compensatory mechanism. *Neurosurgery*. 2017. Epub ahead of print. June 7 2017.
- Ames CP, Smith JS, Scheer JK, et al. Impact of spinopelvic alignment on decision making in deformity surgery in adults. *J Neurosurg Spine*. 2012;16(6):547-564.
- Yagi M, Takeda K, Machida M, Asazuma T. Discordance of gravity line and C7PL in patient with adult spinal deformity—factors affecting the occiput-trunk sagittal discordance. *Spine*. 2015;15:213-221.
- Mizutani J. Cervical reconstruction surgery for cervical kyphosis. *Seikeisaigaikeka (Orthop Surg Transmatol)*. 2015;58:449-457. (In Japanese).
- Mac-Thiong JM, Transfeldt EE, Mehdod AA, et al. Can c7 plumbline and gravity line predict health related quality of life in adult scoliosis? *Spine*. 2009;34(15):E519-E527.
- Roussouly P, Gollogly S, Nosedo O, Berthounaud E, Dimnet J. The vertical projection of the sum of the ground reactive forces of a standing patient is not the same as the C7 plumb line: a radiographic study of the sagittal alignment of 153 asymptomatic volunteers. *Spine*. 2006;31(11):E320-E325.
- 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*. 2006;31(25):E959-E967.
- Sugrue PA, McClendon J, Jr, Smith TR, et al. Redefining global spinal balance: normative values of cranial center of mass from a prospective cohort of asymptomatic individuals. *Spine*. 2013;38(6):484-489.
- Glassman SD, Bridwell K, Dimar JR, Horton W, Berven S, Schwab F. The impact of positive sagittal balance in adult spinal deformity. *Spine*. 2005;30(18):2024-2029.
- Yoshida G, Yasuda T, Togawa D, et al. Craniopelvic alignment in elderly asymptomatic individuals: analysis of 671 cranial centers of gravity. *Spine*. 2014;39(14):1121-1127.