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ORIGINAL ARTICLE

Analysis of cervical sagittal alignment variations after lumbar pedicle subtraction osteotomy for severe imbalance: study of 59 cases

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Abstract

Objective To evaluate postoperative changes within the cervical alignment following surgicallumbar correction by pedicle subtraction osteotomy (PSO) in patients affected with sagittal global malalignment disease.

Methods This was a monocentric, radiographic, and prospective study. 79 patients, who underwent sagittal correction by PSO, performed an EOS imaging pre- and postoperatively between January 2008 and December 2013 at the University Hospital of Bordeaux. Inclusion criteria were a performed pre- and postoperative EOS imaging and a preoperative C7SVA > 5 cm. Were excluded patients who did not allow EOS with a viewable cervical spine due to hyperkyphosis. The study involved the analysis of pelvic, lumbar, thoracic, cervical, and cranial parameters before and after the surgery.

Results 59 patients met the criteria. Mean follow-up was 38 months. The lumbar PSO significantly improved sagittal alignment including L1S1 lordosis, T1T12 kyphosis, and C7SVA ($p < 0.001$). We did not reported a significant change within cervical parameters after PSO (C2C7 lordosis 22.7°–21.5° $p = 0.64$, C1C7 lordosis 50.6°–48.8° $p = 0.56$, C1C2 angle 28.2°–27.9° $p = 0.82$, C7 slope stayed constant 32.3°–30.5° $p = 0.47$, OC2 angle 15.54°–15.56° $p = 0.99$). However, cranial slope decreased significantly ($p < 0.05$). We did not find correlation between lumbar lordosis and cervical lordosis variations ($R = 0.265$). Cervical lordosis was highly correlated with the C7 slope ($R = 0.597$) and with the Spino Cranial Angle ($R = -0.867$).

Conclusion Reciprocal changes in cervical spine after PSO are difficult to approach. Maintaining a horizontal gaze involves locoregional mechanisms of compensation adapting to the slope of C7. The cranial system by decreasing the cranial slope allows the gaze alignment and is the first compensation mechanism to get involved after a loss of lumbar lordosis. Restoring optimal C7SVA is necessary to prevent the development of secondary cervical painful symptomatology when the cranial compensation is outdated.

Keywords Cervical sagittal balance · Lumbar osteotomy · Cervical spine alignment · OD-HA (odontoid-hip axis angle) · PSO (posterior subtraction osteotomy) · PSO consequences

Introduction

The management of spinal deformities requires in some cases pedicle subtraction osteotomies (PSO) to achieve the desired correction. The purpose of PSO is to restore lumbar lordosis to correct spinal alignment and strive for economic sagittal balance.

Klineberg et al. [1] reported a spontaneous increase in thoracic kyphosis on non-instrumented segments after restoration of lumbar lordosis using osteotomy.

Lafage et al. [2–4] showed decreased retroversion of the pelvis after correction of scoliotic deformities with improved SVA (Sagittal Vertical Axis), and this was correlated with significant improvement in health-related quality of life measures. Lafage et al. [4] have noticed the importance of the overall analysis of sagittal balance in the management of spinal deformity as thoracic kyphosis variations, induced by surgery, could compromise the economic restoration of postural balance.

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It is, therefore, essential to understand the postoperative changes caused throughout the spine to better plan sagittal deformity surgery

Some studies have reported the sagittal analysis of the cervical spine after PSO to correct sagittal imbalance [5–8] but with scoliotic deformity. The alignment of the cervical spine maintains a horizontal gaze and this is associated with PSO clinical outcomes [1, 9, 10]. It has been demonstrated that lumbar osteotomy had a cervical clinical impact [11, 12].

We assessed the cervical changes caused by the restoration of a harmonious alignment of the thoracolumbar column after PSO. We hypothesized that patients with a lumbar imbalance maintained horizontal gaze by compensating with cervical hyperlordosis. We assumed that after correcting this imbalance, cervical lordosis would decrease. This work provides the analysis of preoperative and postoperative radiological parameters to improve the understanding of compensating mechanisms between different spine segments in sagittal alignment and spine imbalance.

Methods

Patient selection

This was a radiographic, prospective, and monocentric study at the University Hospital of Bordeaux. 79 patients underwent a PSO surgery by the same surgeon for sagittal imbalance between January 2008 and December 2013. Mean follow-up was 38 months (24–59 months). All patients provided an inform consent as requested by law and local ethic's committee permission obtained.

Inclusion criteria were:

1. Sagittal imbalance with a C7SVA > 5 cm, distance between C7 plumb line and the posterior superior corner of S1 (Fig. 1a) as defined by many authors [5, 9].
2. Odontoid-hip axis angle (OD-HA) [13] defined as the angle between the vertical line crossing the center of the femoral head and a line between the dens on odontoid and the hip axes was always positive and superior to 5° [13] (Fig. 1b).

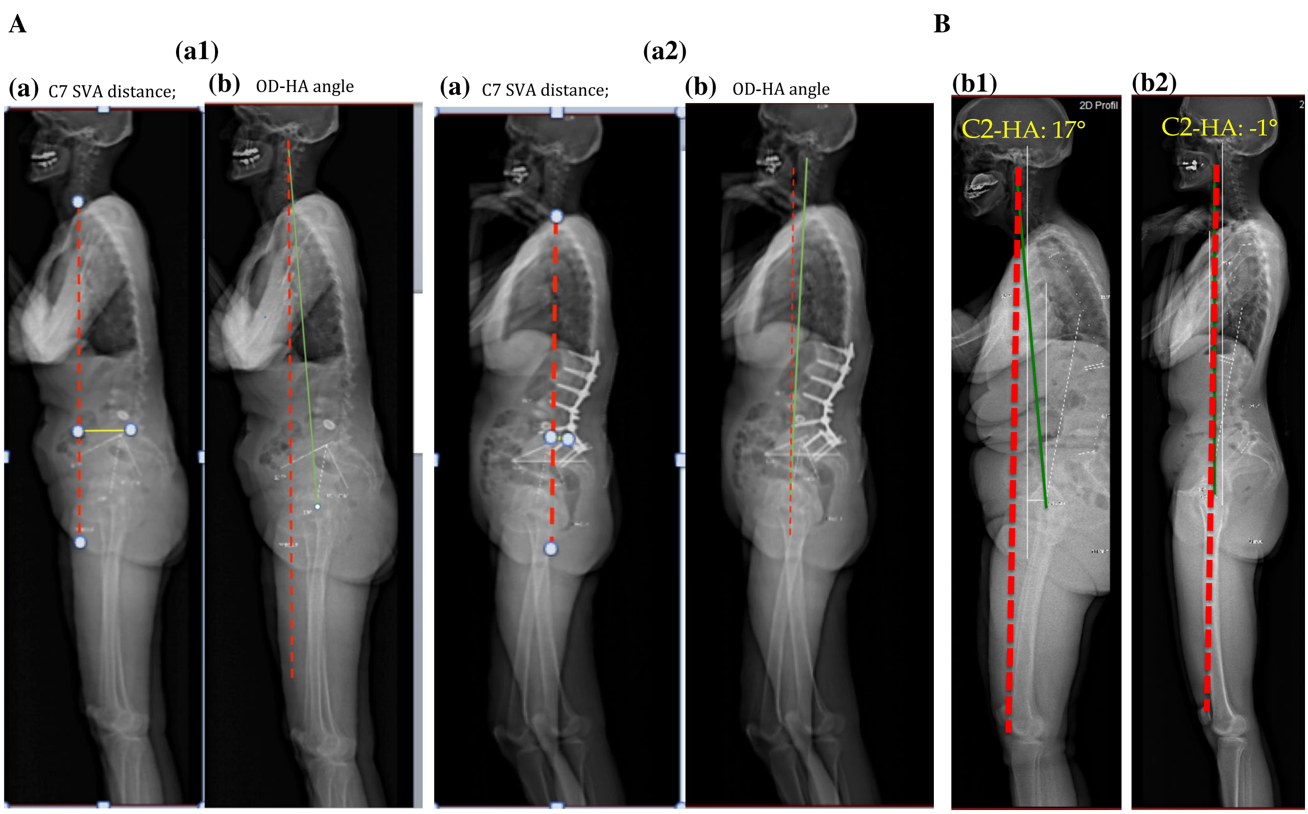

Fig. 1 Preop and postop sagittal balance analysis after lumbar osteotomy correction. A1: preop, A2: postop, B: measurement of OD-HA angle: angle formed between a line from the dens of C2 and the plumb line through the femoral head. B1: abnormal, B2: normal

We excluded patients with a history of cervical spinal surgery, thoracolumbar scoliosis, and those whom the cervical spine was not interpretable on the EOS® radiograph. Cervical spine was analysed clinically for mobility and on X-rays preoperatively, but no flexion/extension X-rays were taken.

All patients had completed pre- and postoperative whole spine EOS® imaging at 3, 6, 12, and 24 months and then at last follow-up or every 2 years. The measures of spinal parameters were carried out from the sterEOS® software (EOS® Imaging, Paris, France) by an independent surgeon who was not involved in the study.

Radiological measurements

The EOS® imaging system was used to obtain a full spine X-ray in a standing standardized position as described by Morvan [14].

Pelvic, lumbar, thoracic, cervical, and cranial parameters were measured pre- and postoperatively (Table 1). The Cobb method was used [15]. The Mc Gregor's line was used as the reference of the skull's base [16]. We used the angles of cranial incidence, cranial tilt, spinocranial angle, C2 tilt, and sella turcica tilt, as described by Le Huec et al. [17]. The occipitocervical junction was analysed by the OC2 angle between the McGregor line and the lower plate of C2.

Changes in radiological parameters were calculated by the difference between the postoperative angles and the preoperative angles, named Δ. To perform a relevant analysis of the effects of the lumbar surgical correction, the population was stratified into sub-groups for a more relevant analysis of the effects of the lumbar surgical correction, in accordance with Barrey et al. [18] in his analysis of an asymptomatic population.

The classification was made according to the pelvic incidence: ≤ 45°, 45–60°, > 60°. This assessed the possible impact of cervical spine changes depending on the back type, as described by Roussouly [19].

Statistical analysis

Statistics were carried out by a bio-statistician. Quantitative values were collected in a descriptive analysis.

Table 1 Definition of all the angles measured in the study

Parameters	Definition
Pelvic	
Pelvic incidence	Angle between the line perpendicular to the sacral plate and the line connecting the midpoint of the sacral plate to the bicoxofemoral axis
Pelvic tilt	Angle between the lines connecting the midpoint of the sacral plate to the bicoxofemoral axis and the vertical plane
Sacral slope	Angle between the sacral plate and the horizontal plane
Lumbar	
L1S1 lordosis	Angle between the upper plate of L1 and S1
Thoracic	
T1T12 kyphosis	Angle between the upper plate of T1 and the lower plate of T12
Cervical	
C2C7 lordosis	Angle between the lower plate of C2 and the lower plate of C7
C1C7 lordosis	Angle between C1 and the lower plate of C7
C1C2 lordosis	Angle between C1 and the lower plate of C2
C7 slope	Angle between the lower plate of C7 and the horizontal plane
SCA	Angle between the line from the sella turcica to the midpoint of C7 and the lower plate of C7
C2 tilt	Angle between the vertical plane from C7 and the lower plate of C2
Turcica sella tilt	Angle between the vertical plane from C7 and the line from C7 to the turcica sella
Cranial	
Mc Gregor line	Line connecting posterior edge of the hard palate to the most caudal point of the occipital curve
Cranial incidence	Angle between the perpendicular at the Mc Gregor line and the line from the middle of the Mc Gregor line and the turcica sella
Cranial tilt	Angle between the vertical plan and the line between the middle of the Mc Gregor line and the turcica sella
Cranial slope	Angle between the horizontal plane and the Mc Gregor line
Global	
C7SVA	Distance between C7 plumb line and the posterior superior corner of S1
Full Balance Integrated	Parameter measuring the global balance of the trunk, either C7 plumb line, the pelvic tilt and the position of the lower limbs
OD-HA	Angle between a vertical line crossing the center of the axis and a line from the dens of C2 to the hip axis

Table 2 Population characteristics: FU: follow-up

	Min	Max	Mean	SD	*p*
Age	29	83	61.1	11.6	NS
BMI	17.6	33.3	25.2	3.6	> 0.05
Tobacco	0	1	0.1	0.3	> 0.05
Follow-up	23.8	56	33.8	8.6	> 0.05
PI	36	86	59	12.8	NS

Correlations were performed when a symmetrical association between two variables was sought. The software used for this analysis was XL-2012 STAT.

Results

Population characteristics

Of the 79 patients that underwent a PSO during the period of inclusion, 59 met all the inclusion criteria (36 were women). 20 patients were excluded because of cervical spine surgery history or a non-viewable cervical spine on the EOS® due to hyperkyphosis. The population characteristics are summarized in Table 2. 27 had long fixation from T4 to pelvis and 32 had shorter construct from T12 or L1 to sacrum. Short construct had no iliac fixation, and 60% of long construct had iliac fixation.

Preoperative to postoperative changes radiographic parameters

Pelvic parameters changed significantly after surgery: L1S1 lordosis, T1T12 kyphosis, and sacral slope increased, while C7SVA and pelvic tilt decreased. The cranial slope decreased significantly. C2C7, C1C7 and C1C2 lordosis, and C7 slope decreased with no significant difference. The angle Occiput C2 remained stable at 15° (Table 3). In the pelvic incidence sub-group analysis, 9 patients were in the group ≤ 45°, 22 in the group 45°–60°, and 28 in the group > 60°. No significant difference in cervical lordosis changes was reported between the three groups (Table 4). The analysis of sagittal balance with the FBI index in the three groups has provided an overall analysis of the correction obtained. The group PI ≤ 45° and 45°–60° group had postoperative Full Balance Index (FBI) < 10° (6.62° ± 9.87 and 10.7 ± 5.47, respectively), while the FBI was > 10° in the group, where PI > 60° (± 15.6 9.82). Similar results were found for the OD-HA correction.

Table 3 Results of all the measures pre- and postop at the last follow-up with *p* value

Parameters	Preop	Postop	*p* value
C7-SVA(cm)	9.11 ± 4.9	4.37 ± 4.6	0.001*
FBI(°)	31.05 ± 13.7	14.72 ± 10.3	0.001*
L1S1(°)	28.9 ± 11.6	49.7 ± 9.0	0.0001*
T1T12(°)	30 ± 11.4	37.4 ± 10.1	0.0001*
SS(°)	29.8 ± 10.5	32.4 ± 8.1	0.12
PT(°)	28.9 ± 10.6	25.2 ± 10.8	0.05*
C2C7(°)	22.7 ± 15.8	21.5 ± 12..4	0.64
C1C7(°)	50.6 ± 16.2	48.8 ± 14.4	0.56
C1C2(°)	28.2 ± 7.5	27.9 ± 8.58	0.82
C7 slope(°)	32.3 ± 14.0	30.5 ± 13.1	0.47
CI(°)	26.1 ± 4.9	24.8 ± 5.2	0.17
CT(°)	10.5 ± 7.9	12.1 ± 12.1	0.29
CS(°)	19.7 ± 11.0	15.6 ± 9.9	0.037*
OC2(°)	15.5 ± 9.5	15.5 ± 8.5	0.99
SCA(°)	71.3 ± 12.0	72.3 ± 9.8	0.62
C2 tilt (°)	15.6 ± 11.4	14.9 ± 12.3	0.75
Turcica sella tilt (°)	14.3 ± 8.6	13.7 ± 9.6	0.7

Results of the correlations between the pelvic, cervical, and cranial parameters

C2C7 lordosis was highly correlated with C7 slope ($R = 0.597$) and SCA angle ($R = -0.867$) (Fig. 2). No correlation was reported between cervical and lumbar variations (Table 5). Cranial slope was highly correlated with cranial tilt ($R = -0.776$) and SCA ($R = 0.559$) (Table 6 and Fig. 3).

Discussion

No study to our knowledge has been published on the balance of the cervical spine after PSO without thoracolumbar scoliosis. This figure is stackable with other similar studies including those of Smith et al. [5], Blondel et al. [8], Ames CP et al. [7], and Ha et al. [6], 75, 76, 31, and 49 patients, respectively, which relate the work of lumbar osteotomy kyphoscoliotic deformation. The average age was 61 years, similar to Smith et al. [5] who reported a mean age of 59 years, Ha et al. [6] 65.2 years, and Blondel et al. [8] 57 years.

The radiographic data were collected with a high quality as all the measurements were done on the SterEOS® software in 2 and 3D. EOS® data are known for their reproducibility and reliability [20]. The best position for balance analysis was reported by Morvan [14] analysing different neutral positions and showing that the best one to avoid changes of spine shape in the standing posture was when finger tips were on the collar bone. The concept of horizontal

Table 4 Pre- and postoperative value of cervical angles according to the value of pelvic incidence, population divided into three groups

PI	*N*	Preop C1C7	Postop C1C7	Preop C2C7	Postop C2C7	Preop OC2	Postop OC2	*p*
≤ 45°	9	46.64 ± 10.59	47.8 ± 11.29	18.02 ± 10.39	18.96 ± 6.63	17.92 ± 10.23	16.66 ± 6.07	> 0.05
45°-60°	22	53.27 ± 17.36	49.02 ± 14.83	25.94 ± 17.58	21.92 ± 12.86	13.98 ± 11.43	14.77 ± 9.21	> 0.05
> 60°	28	49.42 ± 16.93	48.46 ± 15.48	20.85 ± 15.93	21.41 ± 13.45	17.27 ± 7.77	16.01 ± 8.87	> 0.05

There is no significant change in cervical lordosis when in the three sub-groups

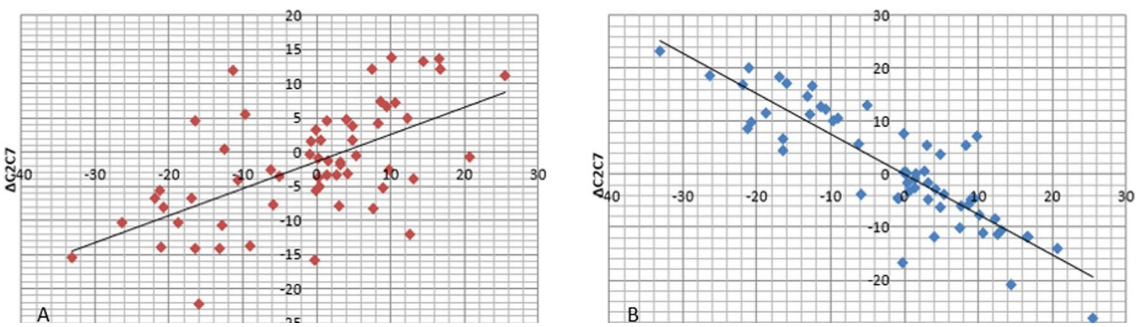

Fig. 2 C2C7 lordosis was highly correlated with C7 slope ($R = 0.597$) and SCA angle ($R = -0.867$)

Table 5 Correlation analysis: no correlation was reported between cervical and lumbar variations

Parameters	Mean ± SD	Pearson
Age	61.1 ± 11.6	− 0.055
ΔC1C7	− 1.7 ± 11.9	0.857
ΔC1C2	− 0.3 ± 5.6	− 0.172
ΔC7 slope	− 1.8 ± 8.3	0.597
ΔOC2	0.01 ± 7.5	0.013
ΔSCA	0.9 ± 11	− 0.867
ΔCI	− 1.2 ± 5.71	− 0.128
ΔCS	− 4 ± 9.84	− 0.462
ΔCT	1.6 ± 8.6	0.121
ΔC7SVA	− 4.74 ± 4.65	0.31
ΔL1S1	20.8 ± 10.4	0.265
ΔT1T12	7.3 ± 11.8	0.288
ΔSS	2.63 ± 8.2	− 0.105
ΔPT	− 3.74 ± 7.3	0.265
ΔOD-HA	11.1 ± 5.1	0.28

Table 6 ΔCranial slope correlations

Parameters	Mean ± SD	Pearson
Age	61.1 ± 11.6	0.002
ΔC1C7	− 1.7 ± 11.9	− 0.526
ΔC1C2	− 0.3 ± 5.6	0.1
ΔC7 slope	− 1.8 ± 8.3	0.064
ΔOC2	0.01 ± 7.5	− 0.1
ΔSCA	0.9 ± 11	0.559
ΔCI	− 1.2 ± 5.71	0.448
ΔC2C7	− 1.2 ± 12.5	− 0.462
ΔCT	1.6 ± 8.6	− 0.476
ΔC7SVA	− 4.74 ± 4.65	0.122
ΔL1S1	20.8 ± 10.4	− 0.08
ΔT1T12	7.3 ± 11.8	− 0.145
ΔSS	2.63 ± 8.2	0.115
ΔPT	− 3.74 ± 7.3	− 0.222

gaze is a reference, but its physiological nature remains controversial. The gravity center of the head allows a horizontal gaze with an orientation of 0°–30° downward [21, 22]. Our latest follow-up was higher than in the other studies which reported a follow-up of 3–6 months [5, 7, 8]. In our study, we reported a minimum of 24 month follow-up (mean 33 months), so the new spine balance could be analysed with a healed paravertebral musculature. The analysis of the FBI index showed that when it was less than 10°, the correction was close to a physiological situation and was correlated with a good functional outcome [23]. When the FBI index is > 10°, the correction was insufficient and low clinical results were achieved. Despite the division into three sub-groups of our series based on the value of the pelvic incidence, we did not find any difference in the variations of postoperative cervical parameters.

Over the last decade, there has been an increasing appreciation of the critical role of sagittal spinopelvic alignment in the maintenance of an economic posture [2, 3, 24–26]; pedicle and interpedicle subtraction osteotomies were mostly used [27–30]. The sagittal balance is a complex phenomenon that involves the pelvic–lumbar–thoracic

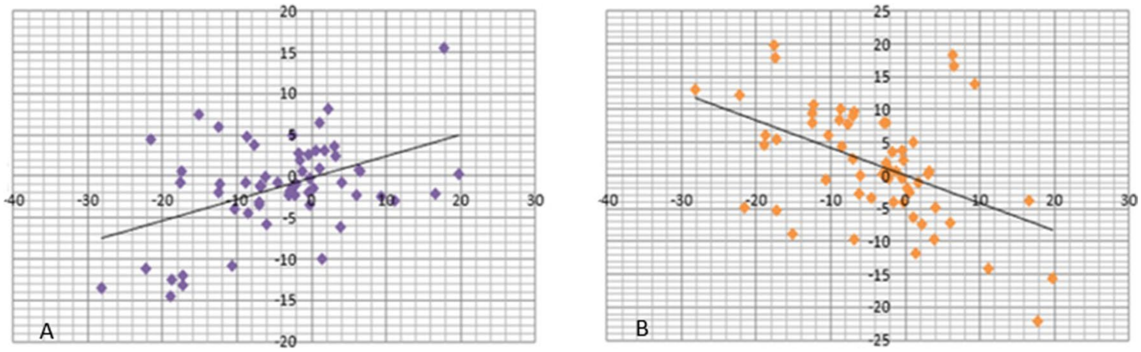

Fig. 3 Cranial slope was highly correlated with cranial tilt ($R = -0.776$) and SCA ($R = 0.559$)

and cervical complex to maintain a horizontal gaze. The correlation between the cervical spine and the pelvis has not been clearly established. The cervical spine supports the skull base. Some studies have established the cranial system's involvement in head posture and its link with the cervical spine [31–34]. Its ability to move independently had also been reported. A degenerative cervical spine or cervical imbalance has a clinical impact as neck pain, radiculopathy, or myelopathy [7, 12]. Understanding cervical spine compensation mechanisms in patients with thoracolumbar deformity is essential to prevent secondary cervical symptoms.

Our study had assumed that C2C7 lordosis would decreased after restoration of lumbar lordosis. Our results did not confirm this hypothesis. We objectified a C2C7 lordosis decrease, but this difference was not statistically significant.

Smith et al. [5] have reported a series in which the loss of cervical lordosis was significant from 30.8° to 21.6°. For this author, the preoperative imbalance was more important with a C7SVA higher than ours. Ha et al. [6], which separated his population into two groups of C7SVA, reports a significant variation of cervical lordosis only in the C7SVA > 9° (30.5°–23°). This result was similar to ours.

Otherwise, our population had a sagittal imbalance without frontal deformity associated, which explains some variations in measurements. Indeed, our mean preoperative lumbar lordosis was 28.9° whereas Smith et al. reported 17°4 [5], and Blondel et al. 19° [8]. It is well known that the lordosis measurement on patients with coronal deformity can be flawed. Radiographic parameters in the other studies did not reported measurements with 3D reconstruction. The measures in this study were performed with the EOS 3D system, which can partly explained the disparity between results. Our study used the 3D reconstructions that avoid distortion and full assessment of C7SVA. Our mean C7SVA was 9.11 cm (± 4.9).

The variation of significant cervical lordosis found by other authors may be due to a possible error of preoperative measures due to the coronal spinal deformation induced scoliosis and measures that were not made in the election plan, then that postoperative measurements were performed on a priori corrected spine in the coronal and frontal plane. Preoperative cervical lordosis measured could also be related to a need for compensation of frontal imbalance related to the scoliosis.

In his work, Ha performed three groups (C7SVA < 6 cm with 21 patients, C7SVA between 6 and 9 cm with seven patients, and C7SVA > 9 cm with 21 patients), the significant change in pre- and postoperative lordosis existed only for the group with C7SVA > 9 cm and in the group where C7SVA < 6 cm variation was reversed. It was, therefore, difficult to draw conclusions especially as the two extreme groups contained only 21 patients. Our series showed a tendency to decrease in cervical lordosis C2C7 but not significant cranial slope and only C7SVA and OD-HA angle were significantly decreased. OD-HA is the only angle paying attention to the head positioning on full spine and, therefore, is a very interesting parameter to analyse the global economic balance.

Analysis of the cervical lordosis reduction after lumbar lordosis and thoracic kyphosis correction could be interesting. We found no correlation between the change C2C7 cervical lordosis and correction of lumbar lordosis (lumbar while the correction is significantly different, 28.9°–49.7 $p < 0.05$) with a coefficient of Pearson 0.265. This result is superimposed on that of the series of Smith et al. [5] with a Pearson coefficient of 0.339 and Ha et al. [6] where it was 0.16. Our series has confirmed the absence of correlation between the return of lumbar lordosis and effect on cervical alignment as the results of the aforementioned authors.

The balance of the cervical spine is related to the anatomy of the cervico-thoracic junction. Lee et al. [36] report in an asymptomatic population, a significant correlation between the slope of T1 and craniocervical balance, a low slope implies a low T1 and vice versa cervical lordosis. The slope of T1 determines the proportion of cervical lordosis necessary to maintain the center of gravity of the head in an equilibrium position and depend on the variation of the overall sagittal balance predicted by the C7SVA and the thoracic kyphosis inherent to the patient.

In their literature review, Ames et al. [7] retrospectively analysed the parameters of the sagittal balance in 55 asymptomatic.

They reported a correlation between the pelvic incidence and lumbar lordosis between the lumbar lordosis and thoracic kyphosis and between the thoracic kyphosis and cervical lordosis. When thoracic kyphosis increased, the cervical lordosis increased ($R = 0.51$). In our study, this correlation was weaker, but still present and positive ($R = 0.288$).

Their results also reported a correlation between the cervical lordosis and pelvic version 0.31, comparable to our results 0.265. By analogy, the C7 slope that can be linked to the T1 slope was more strongly associated in our study with cervical lordosis ($R = 0.597$ against $R = 0.38$). This confirmed the close link between C7 slope and cervical system, making the C7 slope parameter most strongly linked to cervical spine as T1 slope. The C7 vertebra was consistently visible in the EOS® images, whereas T1 is hardly visible in many standard X-rays. The slope of C7 was a key reference for the description of the balance of the cervical spine, easily measurable, and strongly correlated with the cervical lordosis, which confirmed the work of the Huec et al. [17] on the C7 slope achieved in an asymptomatic population.

Smith et al. [5] who analysed a series of patients treated with PSO showed a correlation between the change in thoracic kyphosis and the variation of cervical lordosis and their results were superimposable with our results ($R = 0.339$ and $R = 0.288$, respectively), while the correlation with the T1 slope was 0.621. In our study, the correlation of C2C7 lordosis with C7 slope was 0.597, which was a similar result. Our series reported an average of fused levels of 9.44 [± 3.25, (6–15)]. Smith et al. [5] reported an average of arthrodesis levels of 12 (± 3.7) and found no correlation with the change in cervical lordosis C2C7 ($R = 0.054$). This large number of levels involved arthrodesis probably explains the small changes in thoracic kyphosis. Indeed, a long fusion leaves little room for thoracic and cervical adaptation, whereas a long fusion does not. This highlighted the importance of restoring optimal surgical thoracic kyphosis. Patients with arthrodesis until T4 can compensate their cervical spine only from the variation of the C7 slope imposed by arthrodesis. Arthrodesis up to T12 allowed patients to use a mechanical compensation in connection with the thoracic changes related to the restoration of their lumbar lordosis and have a capacity of extra cervical adaptation. This was probably influenced by the quality of the thoracic back muscles in patients with short fusions.

We can, therefore, conclude that in the compensation mechanisms, there was a locoregional way that was adjusting the cervical segment. The description of an overall compensation mechanism has not been defined in this study.

In our study, the cranial slope decreased postoperatively and was the only criterion to decrease significantly. This showed that to maintain a horizontal gaze after lumbar lordosis restoration, the cranial system represented by cranial incidence, cranial tilt, and the cranial slope [17] is changed first. The patients in our population did not use the cervical system to restore their balance but only the cranial system by decreasing the cranial slope. We can, therefore, assume that in our series, patients restored horizontal gaze after restoration of lumbar lordosis by decreasing the cranial slope. The cranial slope remained linked to cervical ($R = -0462$ between the cranial and cervical lordosis slope) and the latter returned into play when the cranial system was exceeded.

After restoration of lumbar lordosis, patients used their cranial system first by decreasing the cranial slope, cervical adaptation appears as a second compensatory mechanism (Fig. 4).

C2C7 lordosis moderately correlated with the cranial slope ($R = -0462$). No correlation was found between C2C7 lordosis and cranial incidence ($R = -0128$). The variation of cranial slope was correlated with cranial tilt ($R = -0776$) and cranial incidence ($R = 0.448$). This result can define the cranial system which adapts the position of the head independently [17]. Recently, Ajello et al. [35] proposed some rules to determine the appropriate cervical lordosis in preoperative planning.

The angle OC2 was defined between the line of Mc Gregor [16] and the endplate of C2 and allowed the analysis of the occipitocervical junction. Kuntz et al. [37] in his study of occipitocervical fusion stressed the importance of restoring an OC2 angle between 0 and 28°. Indeed, patients with hyperlordotic arthrodesis angle OC2 developed in postoperative kyphosis cervical shape or gooseneck deformity, and those with an OC2 kyphotic angle were associated with the development of an underlying subluxation. Therefore, we understand the importance of knowing the normal value of this angle to plan the best cervical surgeries. In our series, we found a strictly steady OC2 angle 15.5° (± 9) before and after lumbar adjustment, a result comparable to that measured in the asymptomatic population of Le Huec et al. [17] (15.81° ± 7.15). This result validated the consistency of this angle and corroborated the results of other authors [37, 38] on the need to restore an OC2 angle between 0 and 30° in the occipitocervical arthrodesis surgery.

Finally, recent studies have been conducted on clinical effects and impaired quality of life of patients with cervical strain [12, 39, 40]. In our study, we did not report preoperative clinical score for neck pain. A complementary study prospectively collecting cervical disability scores before lumbar transpedicular osteotomy correction would be necessary to assess the improvement in postoperative cervical

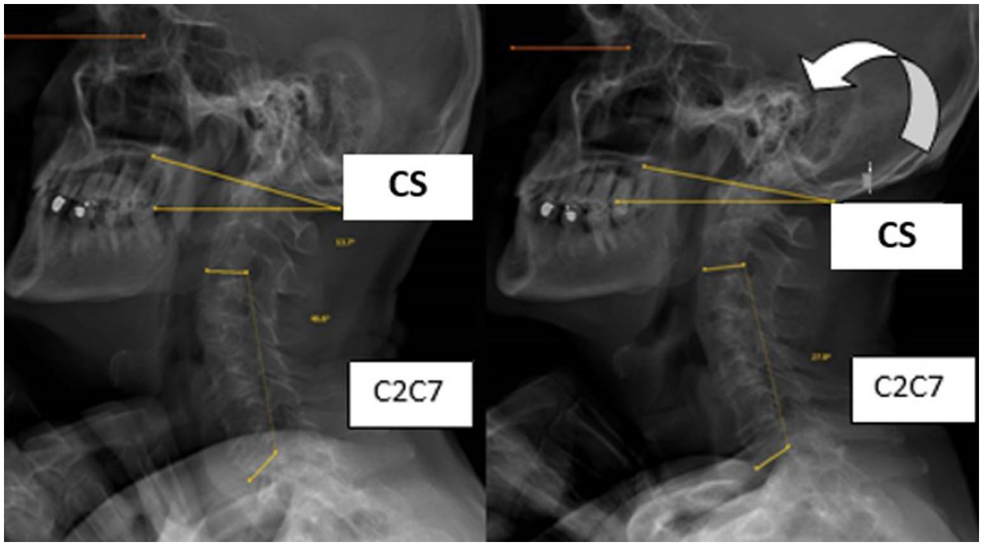

Fig. 4 Case example. Cranial slope (CS) decreased after surgery

symptomatology related to restoring the balance of the cervical spine.

Compliance with ethical standards

Conflict of interest None of the authors has any potential conflict of interest.

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