

Cervical spine balance: postoperative radiologic changes in adult scoliosis surgery

Louis Boissière · Jean Bernard · Jean-Marc Vital ·
Vincent Pointillart · Rémi Mariey · Olivier Gille ·
Ibrahim Obeid

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Abstract

Purpose Cervical spine alignment interests appeared recently and relationships between the pelvis and the cervical spine have been reported but remain unclear. In this study, postoperative changes for cranial, cervical, lumbar and sagittal balance parameters have been measured in adult scoliosis surgery without major sagittal malalignment to appreciate the adaptation of the cervical spine.

Methods Twenty-nine consecutive patients with a surgical adult degenerative scoliosis treated with a T8–T11 to iliac fusion without PSO or multiple Ponte's osteotomies had preoperative and postoperative full spine EOS radiographies to measure spino-pelvic parameters. Correlation analysis between the different parameters was performed.

Results Lower cervical, lordosis, lumbar lordosis and thoracic kyphosis were increased in postoperative as no changes were observed for upper cervical lordosis. C1–C7 CL highly correlated (0.85 in preoperative and 0.87 in postoperative) with C7 slope, which highly correlated itself with global balance parameters (0.74 in preoperative and 0.71 in postoperative for CAM-PL) underlining the relationship between cervical spine alignment and global malalignment.

Conclusions Modifications of lower CL are observed, as upper CL remains constant. If no correlation was found for LL, TK and CL changes, CL appears to be highly correlated with C7 slope, which highly correlated itself with sagittal global balance parameters. C7 slope appears as a base for CL influenced by the spine global alignment.

Keywords Cervical spine alignment · Adult scoliosis · C7 slope · Cervical lordosis

Introduction

In adult scoliosis sagittal alignment, the relationship between pelvic incidence (PI) and lumbar lordosis (LL) has widely been studied [1, 2]. Cervical spine alignment (CSA) interest appeared more recently. If the natural curvature of the cervical spine maintains a lordotic shape [3], cervical spine kyphotic alignment exists for 2–35 % of asymptomatic patients [4–6]. Through the lifespan, cervical spine undergoes progressive changes with a positive correlation between cervical lordosis (CL) and increasing age [4, 7]. These observations suppose a large variability for CSA and its scalability in the normal population but its adaptive mechanisms remain unclear.

Some authors supposed that the cervical spine had its own mechanism to preserve physiological sagittal alignment [6] as others reported that CL was significantly influenced by thoracic kyphosis (TK) [7]. Demezou [8] studied the relationship between C7 slope and other sagittal parameters. He reported a significant correlation between the C7 slope, sacral slope (SS) and CL in asymptomatic population. These correlations underline the relationships between the pelvis and the cervical spine. Few reports evaluated CSA and postoperative changes in adult scoliosis. In severe spinal malalignment, to maintain horizontal gaze, abnormally increased CL is observed. The correction of the sagittal malalignment following lumbar PSO can result in correction of the abnormal cervical hyperlordosis through reciprocal changes as the correlation between sagittal malalignment correction and CL is negative [9]. On the opposite, junctional kyphosis will lead to an increased CL [10].

L. Boissière (✉) · J. Bernard · J.-M. Vital · V. Pointillart ·
R. Mariey · O. Gille · I. Obeid
Spine Unit 1, Orthopedic Surgery Department, Bordeaux
Pellegrin Hospital, Place Amélie Raba Léon, Bordeaux, France
e-mail: boissierelouis@yahoo.fr

These considerations underline the relationships between the different spinal curves. The purpose of this study was to observe the relationships between cranial, cervical, lumbar and sagittal balance parameters in adult lumbar scoliosis with moderate spinal malalignment and evaluate postoperative changes to appreciate the cervical spine adaptation.

Materials and methods

Patient selection

Inclusion criteria were adults over 50 years old with a degenerative lumbar or thoracolumbar scoliosis with a minimum Cobb angle of 15° requiring an extensive fusion from T8–T11 to ilium. Exclusion criteria were previous spine surgery with fusion, neurologic disease (Parkinson), scoliosis treated by spinal Pedicle Subtraction Osteotomy (PSO) or more than one Ponte osteotomie. All eligible patients were included in this study. All patients were instrumented the same way with polyaxial pedicular screws at all levels, iliac screws and pediculo-transversal hooks at the proximal instrumented level.

Radiological parameters

All patients had preoperative and postoperative full length standing radiographs with EOS low-dose system (Biospace, Paris, France) [11]. The postoperative EOS was analyzed at 6 months follow-up. All patients had a postoperative brace for 3–6 months and the EOS was realized after brace removal. Posture in the EOS device was in an easy standing position with fists overlaying ipsilateral clavicles. All angles were measured by the Cobb method. The following spino-pelvic parameters were measured using validated software (Spineview, Surgiview) [12]:

- Pelvic parameters: Pelvic incidence (PI), Pelvic tilt (PT), Sacral slope (SS).
- Cranial parameter:
 - C0–C2 angle: angle between the Mac Gregor line and the C2 lower endplate.
- Cervical parameters:
 - Cervical lordosis (CL): C1–C7 angle.
 - Upper cervical lordosis: C1–C2 angle.
 - Lower cervical lordosis: C2–C7 angle.
 - C7 slope: angle between the horizontal line and C7 upper endplate.
 - Neck tilt: angle between the vertical line to the midpoint of C7 upper endplate and the line connecting this point to CAE.

- Thoracolumbar parameters: thoracic kyphosis (TK) (T1–T12 angle), lumbar lordosis (LL) (L1–S1 angle).
- Global balance parameters
 - Sagittal vertical axis (SVA).
 - Center of both Acoustic Meati Plumb Line (CAM-PL): distance in millimeters between CAM overhang and the posterior corner of top margin of S1. CAM overhang gravitates from –2 to 2 cm around the center of the femoral heads in an asymptomatic adult population [13]. To allow comparisons with SVA and analyze CSA, we used CAM-PL as described above.

All sagittal measurements were considered positive if the curve was lordotic and negative if the curve was kyphotic.

Statistical analysis

Paired samples *t* tests were used to compare pre- and postoperative radiographic measurements. Correlations between radiographic parameters were performed using the Pearson correlation coefficient. A $p < 0.05$ was considered to be significant. All statistical analyses were conducted using the SPSS software (IBM SPSS, Inc.).

Results

The study included 29 patients, from a single center, included prospectively between June 2009 and June 2013. There were 27 female and 2 male patients with an average age of 64.3 years (range 51–79). The mean Cobb angle was 27.7° (range 15–51).

Population description (Table 1)

Pelvic parameters

PI was 55.0° (mean value) in preoperative and 55.4° in postoperative. PT was 26.9° in preoperative and 26.8° in postoperative. SS was 28.1° in preoperative and 28.6° in postoperative. There were no statistical differences for all these values.

Thoracolumbar parameters

LL was 37.7° in preoperative and 47.8° in postoperative. TK was –33.5° in preoperative and –45.5° in postoperative. The differences were statistically different for both parameters.

Table 1 Population description

Measurement	Preoperative	+6 months	<i>p</i>
Pelvic incidence (°)	55.0 (±13.2)	55.4 (±12.1)	0.84
Pelvic tilt (°)	26.9 (±9.3)	26.8 (±8.8)	0.95
Sacral slope (°)	28.1 (±9.9)	28.6 (±8.9)	0.71
Lumbar lordosis (°)	37.7 (±13.1)	47.8 (±8.6)	<0.001
Thoracic kyphosis (°)	−33.5 (±12.7)	−45.5 (±14.4)	<0.001
SVA (mm)	41.6 (±44.2)	35.6 (±35.4)	0.50
CAM-PL (mm)	51.4 (±52.0)	40.2 (±42.7)	0.23
C0–C2 angle (°)	16.1 (±6.9)	14.3 (±8.3)	0.20
Cervical lordosis (°)	43.1 (±13.5)	46.9 (±12.0)	0.08
Upper CL (C1–C2) (°)	31.7 (±6.9)	32.1 (±7.1)	0.7
Lower CL (C2–C7) (°)	10.6 (±14.5)	14.6 (±14.1)	0.03
C7 slope (°)	22.6 (±10.6)	24.2 (±10.1)	0.2
Neck tilt (°)	−1.2 (±7.6)	1.5 (±6.2)	0.04

Global balance parameters

SVA was 41.6° mm in preoperative and 35.6° mm in postoperative. CAM-PL was 51.4 mm in preoperative and 40.2 mm in postoperative. No statistical difference was found for these parameters.

Cranial parameter

C0–C2 angle was 16.1° in preoperative and 14.3° in postoperative. No statistical difference between these two values was found.

Cervical parameters (Fig. 1)

CL was 43.1° in preoperative and 46.9 in postoperative. Upper CL (C1–C2) was 31.7° in preoperative and 32.1° in postoperative. Lower CL (C2–C7) was 10.6° in preoperative and 14.6° in postoperative. C7 slope was 22.6° in preoperative and 24.2° in postoperative. Neck tilt was −1.2° in preoperative and 1.5° in postoperative. As no statistical differences were found for CL, upper CL and C7 Slope; neck tilt and lower CL were statistically different.

Correlation between LL, TK and CL operative changes (Table 2)

The changes for LL were evaluated by the following formula:

- (Preoperative LL–postoperative CL)/preoperative LL

The same ratio was performed for TK and lower CL. No correlation was found between LL, TK and lower CL changes.

Correlation analyses for C7 slope and lower CL in preoperative (Table 3)

Lower CL

- High correlation was found (>0.5) with: CL, C7 slope and SVA.
- Low correlation was found (<0.5) with: PT and CAM-PL.
- No correlation was found (NS) with: PI, SS, TK, LL, C0–C2 and NT.

C7 slope

- High correlation was found (>0.5) with: CAM-PL, SVA, CL, and Lower CL.
- Low correlation was found (<0.5) with: TK.
- No correlation was found (NS) with: PI, PT, SS, LL, C0–C2, NT.

Correlation analyses for C7 slope and CL in postoperative (Table 4)

Lower CL

- High correlation was found (>0.5) with: C1–C7, C7 slope
- Low correlation was found (<0.5) with: C0–C2.
- No correlation was found (NS) with: PI, PT, SS, LL, TK, SVA, CAM-PL, NT.

C7 slope

- High correlation was found (>0.5) with: SVA, CAM-PL, C1–C7, C2–C7.
- Low correlation was found (<0.5) with: TK
- No correlation was found (NS) with: PI, PT, SS, LL, C0–C2, NT.

Correlation analyses between SVA and CAM-PL

The Person correlation rank factor for SVA and CAM-PL was 0.96 in preoperative and 0.95 in postoperative ($p < 0.001$).

Discussion

Changes in CSA after extensive fusions are reported in literature [9, 14]. In our study, all patients presented a lumbar scoliosis, with a moderate spinal malalignment, treated with an extensive fusion from T8/T11 to ilium. No differences were observed between preoperative and postoperative for PT, SS, SVA, and CAM-PL illustrating the moderate changes in spinal malalignment. On the other

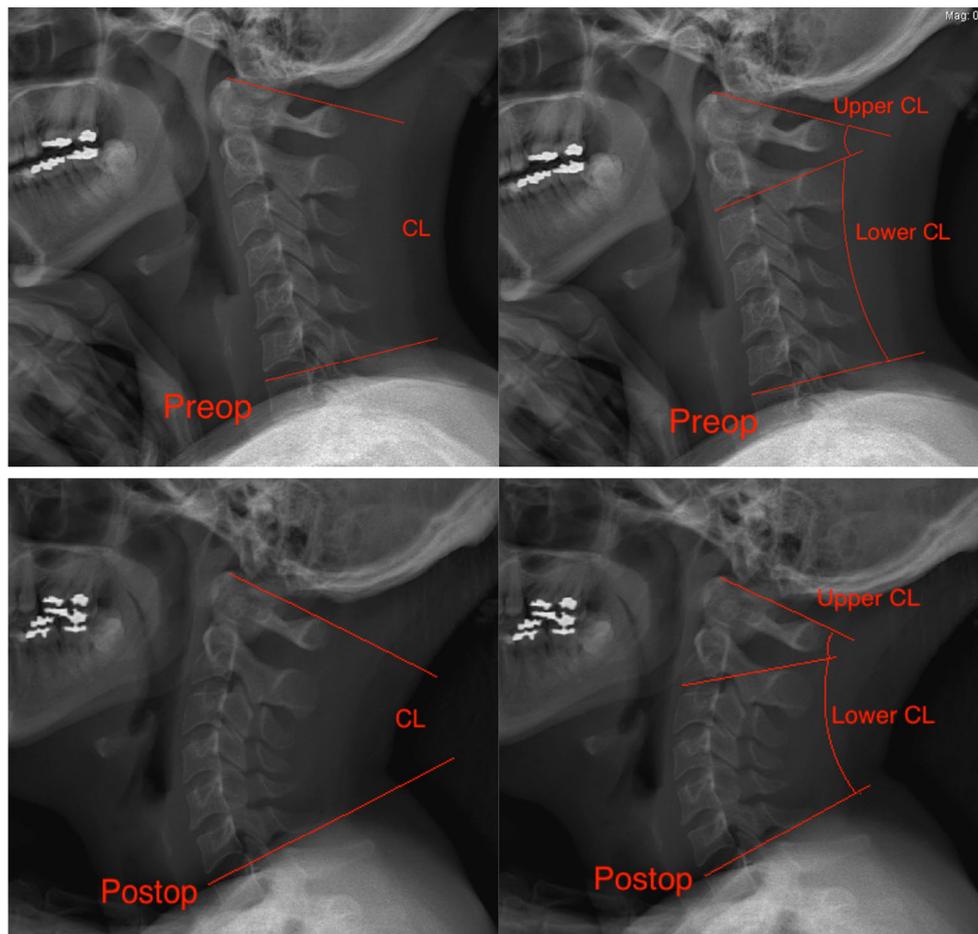


Fig. 1 Preoperative and Postoperative CL, Upper CL and Lower CL. CL and Lower CL are increased, as Upper CL remains constant

Table 2 Correlation between LL, TK and CL operative changes

Correlation	LL changes	<i>p</i>	TK changes	<i>p</i>	CL changes	<i>p</i>
LL changes	1		0.2		0.2	
<i>p</i>				0.4		0.4
TK changes	0.2		1		-0.1	
<i>p</i>		0.4				0.9
CL changes	0.2		-0.1		1	
<i>p</i>		0.4		0.9		

end, significant changes are observed for LL, TK, CL underlining that spinal alignment adjusts itself, for the non-fused part of the spine, even if global balance is not modified (no changes for SVA, CAM-PL). Modifications in CL after scoliosis surgery have already been reported when TK increases in AIS surgery after correction of thoracic hypokyphosis [14] and a parallel could be drawn with our series.

In our results, changes in CL exclusively concerned lower CL, as upper CL remained constant after surgery. If the mean changes for lower CL is of 4°, it represents a mean raise of 40 % of lower CL. We can consider lower

CL, which represents 25 % of static total CL, as the only factor influencing CSA and as the last adaptation factor to maintain horizontal gaze in this study. Relationships between upper and lower cervical lordosis have already been reported [15]. Normal motion of cervical spine has already been studied in anatomic and biomechanical studies, C0–C2 motion represents up to 45 % of normal cervical motion [16], this motion is not observed for CSA adaptation. An explanation we can bring is that in our series all patients presented a moderate spinal malalignment with a lumbar origin; it would be interesting to study the relationships between upper and lower CL in severe malalignment to

Table 3 Correlation analyses for C7 slope and Lower CL in preoperative

Preoperative	Lower CL (°)	<i>p</i>	C7 slope (°)	<i>p</i>
PI (°)	0.21	NS	-0.08	NS
PT (°)	0.41	<0.05	0.18	NS
SS (°)	-0.10	NS	-0.27	NS
LL (°)	-0.10	NS	-0.19	NS
TK (°)	0.24	NS	0.45	<0.01
SVA (mm)	0.53	<0.001	0.68	<0.001
CAM-PL (mm)	0.45	<0.001	0.74	<0.001
C0–C2 (°)	-0.31	NS	-0.13	NS
C1–C7 (°)	0.85	<0.001	0.59	<0.001
C2–C7 (°)	1		0.67	<0.001
C7 slope (°)	0.67	<0.001	1	
NT (°)	0.21	NS	-0.43	NS

Table 4 Correlation analyses for C7 slope and Lower CL in postoperative

Preoperative	Lower CL (°)	<i>p</i>	C7 slope (°)	<i>p</i>
PI (°)	0.13	NS	0.10	NS
PT (°)	0.01	NS	0.10	NS
SS (°)	0.17	NS	0.03	NS
LL (°)	0.21	NS	0.01	NS
TK (°)	0.34	NS	0.40	0.04
SVA (mm)	0.36	NS	0.61	<0.01
CAM-PL (mm)	0.32	NS	0.71	<0.01
C0–C2 (°)	-0.40	0.03	0.25	NS
C1–C7 (°)	0.87	<0.01	0.72	<0.01
C2–C7 (°)	1		0.69	<0.01
C7 slope (°)	0.70	<0.01	1	
NT (°)	0.23	NS	0.33	NS

observe if upper CL is involved. To our knowledge, this is the first published study to report a differential adaptation of CSA between upper and lower CL.

If changes in lower CL are observed, we tried to understand the mechanism. No correlation was found between changes in LL, TK and lower CL. If LL, TK and CL increased, no relationship was found between these values (Table 2). Lower CL highly correlated in preoperative and in postoperative with C7 slope, a parameter reported by Demezon [8]. The correlation was 0.85 in preoperative and 0.87 in postoperative with C1–C7 CL. This positive correlation underlines the fact that patients with a small C7 slope will have a small CL and patients with a high C7 slope will have an increased CL. Lee et al. [6] described similar results with the T1 slope and introduced the notion that CSA had its own adaptive mechanism guided by the Thoracic Inlet. Modifications of

lower CL have also been studied after cervical laminoplasty [17]. The authors mentioned the correlation between T1 slope and lower CL and introduced the notion of uncompensated CSA. More kyphotic changes were observed for patients with height lower CL, favoring cervical malalignment occurrence. Postoperative T1 slope was not evaluated, and was considered by the authors as a morphologic parameter.

If we did not find any support for Demezon's observation in this series, with an absence of correlation between C7 slope and SS for preoperative or postoperative values, C7 slope highly correlated with global balance parameters (SVA, CAM-PL) and moderately with TK for preoperative and postoperative values. C7 slope seems to be an adaptive parameter, influenced by global malalignment and highly correlated to CL. These relationships between CSA and Global Balance Parameters have already been reported by Roussouly et al. [18], CSA seems to adapt itself to maintain horizontal gaze to global spine balance. C7 slope seems to be a base for CL. This important correlation with global malalignment gives less support to Lee's hypothesis where CSA has its own adaptive mechanism. Indeed local operative damage, such as laminoplasty for example, will result in local changes but CSA is also influenced by global balance.

The high correlation between SVA and CAM-PL in preoperative and in postoperative underlines the fact that the distance between the cranium and C7 body, representing global CSA, is not modified. Modifications of lower CL always preserve the global alignment with the aim to maintain horizontal gaze and the head gravity center above C7 body represented by the NT close to 0° [19].

A limit of our study is the number of patients included. Major surgeries without spinal osteotomies in an adult population made us exclude a large number of patients. With 29 patients, we already revealed many statistical significant results and answered part of our question concerning CSA. Further studies concerning other degenerative spinal diseases will help us understand the adaptive mechanism of the cervical spine and how CL and C7 slope are related to the rest of the spine.

Conclusion

Cervical Sagittal Alignment interest appeared recently. Our study demonstrates that modifications of lower CL are observed, as upper CL remains constant. If no correlation was found for LL, TK and CL changes, CL appears to be highly correlated with C7 slope, which highly correlated itself, with sagittal global balance parameters. C7 slope appears as a base for CL influenced by the spine global alignment.

Conflict of interest The authors declare that they have no conflict of interest.

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