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Changes in cervical sagittal balance following anterior cervical discectomy with fusion

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ABSTRACT

Introduction. Change in the sagittal balance after anterior cervical discectomy with fusion (ACDF) is a phenomenon that has not yet been sufficiently studied. The aim of this study was to assess such changes.

Material and methods. 28 patients who underwent ACDF for cervical spondylosis were examined. The study was divided into three stages: preoperative, early postoperative, and late postoperative. Sagittal alignments were analysed based on X-ray AP and lateral images: angles C1-C7, C2-C7, C1-C2, C1-C4, C4-C7 and cervical sagittal vertical axis (cSVA).

Results. The cervical lordosis C2-C7 decreased by 13% in early monitoring, after which it increased by 60% in the late postoperative phase. Post hoc analysis showed that the measured values between early and late postoperative monitoring differed significantly. Cervical sagittal vertical axis (cSVA) increased by 23% in early control and then decreased by 18% in the late postoperative phase. Post hoc analysis showed that the measured values significantly differed between preoperative and early postoperative monitoring, and between early and late postoperative monitoring.

Conclusions. We have shown that the long-term effect of ACDF is correction of the sagittal balance of the cervical spine. Immediately after the procedure, a disturbance in the cervical spine curvature to the morphology of the entire spine is observed.

Keywords: postural balance, spine, spondylosis, cervical spine, anterior cervical discectomy with fusion, biomechanics

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Introduction

Recent years have seen important advances regarding the understanding of sagittal balance (SB) changes following surgical treatment of cervical spondylosis by anterior cervical discectomy with fusion (ACDF) [1–6].

A relationship between ACDF and an increase in the cervical lordosis angle, or a decrease in the kyphosis angle, has been proven [1–3, 5–10]. The same effect of ACDF on the angle of the fused segment has also been demonstrated [1–3, 5, 6, 8].

The summarised conclusions have allowed the hypothesis to be put forward that primary correction of the sagittal balance on the segments operated on positively correlates with an improvement of the position of the entire cervical spine [1, 6]. However, it is not clear whether the improvement in the global setting is related to the surgery itself. According to some authors, it occurs over time [1–3, 5, 6]. However, other results indicate a slight decrease in the described angles during the observation period [2, 3]. The decrease is more clearly expressed in the case of measurements of the curvature of the entire cervical spine as a fused segment [1, 2]. It has been proved that the cervical lordosis correction degree after ACDF may depend on the type of interbody implant used, but their final effect remains unclear [2, 3, 11]. The relationship between the use of the anterior plate and the correction of the sagittal balance is also debatable [1, 2]. However, it has been

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shown that the degree of cervical lordosis angle improvement positively correlates with the length of stabilisation [1, 2]. Other analyses have shown that more correction is achieved in patients with more advanced preoperative disorders of the sagittal balance [12, 13].

The cervical lordosis angle has a negative correlation with the cervical sagittal vertical axis (cSVA) [6] A 10% increase in cSVA after ACDF has been observed [6, 14]. A cadaver study showed that a postoperative increase in biomechanical loads on the levels adjacent to stabilisation increased with increasing cSVA [15]. As the sagittal imbalance of the cervical spine progresses, the biomechanical loads observed in the intervertebral discs are likely to increase.

Postoperative changes in cervical spine angles affect the effects of treatment. A relationship between lordosis correction and improved patient condition has been demonstrated [5, 16, 17]. In the case of cSVA, both pre- and postoperative values are an independent prognostic factor of treatment effectiveness. The majority of patients with cSVA > 40 mm achieve positive treatment effects only in terms of myelopathy symptoms [14]. An effect of ACDF on the global sagittal balance of the spine has also been observed. Decreased sagittal vertical axis (SVA), increased pelvic tilt (PT), and decreased sacral slope (SS) have been observed in patients with a large preoperative cervical lordosis angle [17].

The aim of this study was to make a comprehensive assessment of changes in the sagittal balance of the cervical spine after ACDF.

Material and methods

28 patients who underwent ACDF for cervical spondylosis at the Department of Neurosurgery and Paediatric Neurosurgery at the Pomeranian Medical University in Szczecin, Poland from March 2012 to June 2013 were examined. The retrospective case study protocol was approved by the Institutional Review Board. All subjects gave informed consent for treatment and additional tests. The PROCESS reporting guideline has been implemented.

The group consisted of 22 women and six men. Their average age was 51 years (range: 31–61, SD 7.69). All patients were operated on by the same surgeon, Prof. Leszek Sagan. PEEK parallel interbody cages and titanium lordotic anterior plates were used. The study was divided into three stages. The first (preoperative) took place on the day preceding the procedure in 28 patients included in the assessment, the second (early postoperative) along with routine postoperative monitoring between the 4th and 5th days after surgery in 27 patients, and the third (late postoperative) with routine outpatient follow-up of on average 38 months (range: 11–46, SD 7.83), in 24 patients. Descriptive statistics for the ages and the intervals between study stages are set out in Table 1. The diminishing number of patients included in each subsequent stage of the study was a result of difficulty in continuing regular follow-up visits. Missing data was supplemented by substituting the arithmetic mean of individual parameters.

Table 1. Descriptive statistics for age and time between preoperative and late postoperative stages

Feature	Mean	Min	Max	SD
Age [years]	51.29	31.0	61.0	7.69
Time [months]	37.71	11.0	46.0	7.83

Classic X-ray images taken in clinical practice were used for the analysis. AP and lateral images taken at each stage of the study were evaluated. All images were obtained using an AXIOM Aristis FX digital RTG camera (Siemens Healthcare). Patients were placed in Morvan's standard position for sagittal imaging. The patients assumed a natural, upright posture, standing barefoot, with their feet slightly apart, with straight knees, with their upper limbs hanging down freely [18]. The posture was not modified by raising their hands on the photo projection supports.

The sagittal balance of the cervical spine was defined as the angle of curvature C1-C7. The segment C1-C7 was divided into upper parts C1-C2, C1-C4, and lower parts C2-C7, C4-C7. The widely recognised Cobb angle method was used to measure curvatures [19–23]. This method involves running four straight lines. Depending on the analysed parts, horizontal lines run between the anterior and posterior C1 nodules, parallel to the lower endplate of C2, C4 or C7. Then vertical straight lines are drawn perpendicular to the appropriate horizontal ones, and the angle formed by their intersection determines the value of the curvature. Lordosis is defined as positive angles, and kyphosis as negative.

The cervical sagittal vertical axis was determined by measuring the horizontal distance between the C2 plumb line (C2PL), i.e. the vertical straight line passing through the centre of the C2 body, and the upper-posterior corner of the C7 body [6, 14–16].

The drawing of lines and the calculation of angles were made using the Surgimap program (Nemaris, Inc.) distributed with a freeware licence. The algorithms included in this program allow the precise and repeatable determination of spinal osteometric parameters [24, 25].

Descriptive statistics were used in the statistical analysis, wherein mean, standard deviation, minimum, and maximum values were calculated. The arithmetic average method was used to fill in the missing data. Assumptions regarding the normality of the distribution of quantitative variables were checked using the Shapiro–Wilk test. The differences between the values of the collected features before and after the operation were calculated using Friedman's ANOVA and post hoc tests. Correlations were established using the Pearson linear correlation coefficient. The results were considered significant at $p < 0.05$. Calculations were carried out using Statistica 12 (StatSoft).

Table 2. Descriptive statistics of sagittal balance parameters and p-values for Friedman's ANOVA test, examining differences in cervical lordosis angles between individual stages of study

Feature	Mean	Min	Max	SD	P-value
SB C2-C7 preop. [°]	11.62	–11.0	34.0	12.73	**p = 0.014**
SB C2-C7 postop. 1 [°]	10.12	–12.0	24.0	6.76	
SB C2-C7 postop. 2 [°]	16.25	3.0	31.0	7.84	
SB C1-C7 preop. [°]	38.46	15.0	67.0	12.85	p = 0.285
SB C1-C7 postop. 1 [°]	37.19	15.0	51.0	7.70	
SB C1-C7 postop. 2 [°]	41.79	12.0	63.0	12.90	
SB C1-C2 preop. [°]	26.12	15.0	36.0	6.02	p = 0.433
SB C1-C2 postop. 1 [°]	27.12	15.0	41.0	5.81	
SB C1-C2 postop. 2 [°]	26.92	14.0	37.0	6.08	
SB C1-C4 preop. [°]	29.73	13,0	47.0	9.28	p = 0.953
SB C1-C4 postop. 1 [°]	26.96	–9.0	40.0	10.46	
SB C1-C4 postop. 2 [°]	28.46	–13.0	50.0	12.37	
SB C4-C7 preop. [°]	8.23	–13.0	35.0	10.69	p = 0.272
SB C4-C7 postop. 1 [°]	8.73	–2.0	19.0	5.81	
SB C4-C7 postop. 2 [°]	10.83	–2.0	35.0	8.29	
cSVA preop. [mm]	22.00	3.2	45.4	10.08	**p = 0.007**
cSVA postop. 1 [mm]	27.12	9.5	41.5	9.51	
cSVA postop. 2 [mm]	22.04	5.4	48.9	10.54	

SB — sagittal balance

Results

The average cervical lordosis angle C2-C7 was 11.6° (–11.0 to 34.0; SD 12.7) preoperatively, 10.1° (range: –12.0 to 24.0; SD 6.8) in early postoperative monitoring, and 16.3° (range: 3.0 to 31.0; SD 7.8) in late postoperative monitoring. C1-C7 values were 38.5° (range: 15.0 to 67.0; SD 12.8) in the 1st stage of the study, 37.2° (range: 15.0 to 51.0; SD 7.7) in the 2nd stage, and 41.8° (range: 12.0 to 63.0 ; SD 12.9) in the 3rd stage. C1-C2 were 26.1° (range: 15.0 to 36.0; SD 6.0) preoperatively, 27.1° (range: 15.0 to 41.0; SD 5.8) in early postoperative monitoring, and 26.9° (range: 14.0 to 37.0; SD 6.1) in late postoperative monitoring. C1-C4 were 29.7° (range: 13.0 to 47.0; SD 9.3) in the 1st stage, 26.9° (range: –9.0 to 40.0; SD 10.5) in the 2nd stage, and 28.5° (range: –13.0 to 50.0; SD 12.4) in the 3rd stage. C4-C7 were 8.2° (range: –13.0 to 35.0; SD 10.7) preoperatively, 8.7° (range: –2.0 to 19.0; SD 5.8) in early postoperative monitoring, and 10.8° (range: –2.0 to 35.0, SD 8.3) in late postoperative monitoring. The average cSVA values were 22.0 mm (range: 3.2 to 55.4; SD 10.1) in the 1st stage, 27.1 mm (range: 9.5 to 41.5; SD 9.5) in the 2nd stage, and 22.4 mm (5.4 to 48.9; SD 10.5) in the 3rd stage. Detailed values of the cervical lordosis angle of the studied sections and cSVA, as well as p-values for the differences before and after ACDF, are set out in Table 2. Figure 1 shows the correction of the sagittal balance of the cervical spine by increasing the lordosis angle.

A statistically significant difference was found in the cervical lordosis angle before and after ACDF in C2-C7 (p = 0.014). In relation to the preoperative stage, this angle decreased by 13% in early postoperative monitoring, and then increased by 60% in the late postoperative stage compared to the early monitoring (Fig. 2). Post hoc analysis showed statistically significant differences in the value of the cervical lordosis angle between early and late postoperative monitoring (Tab. 3). There was no statistically significant difference in cervical lordosis angles in other cervical spine sections after ACDF.

A statistically significant difference was found in the cSVA values before and after ACDF (p = 0.007). Compared to the preoperative stage, this parameter increased by 23% in early postoperative monitoring, and then decreased by 18% in the

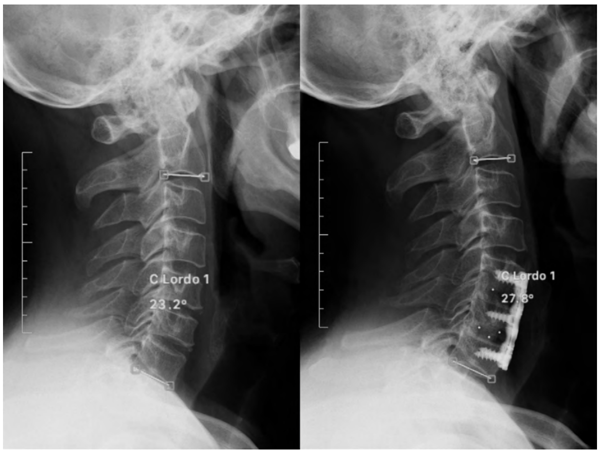

Figure 1. Lateral, pre- and late postoperative X-rays showing correction of sagittal balance of cervical spine by increasing lordosis angle

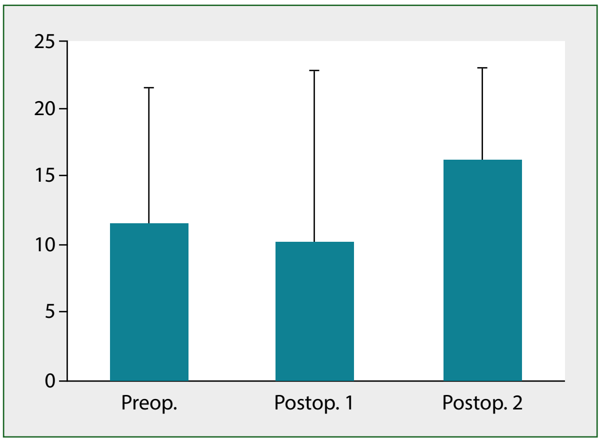

Figure 2. Distribution of C2-C7 lordosis angle values at three different time intervals. Postop. 1 means early postoperative monitoring, and postop. 2 means late postoperative monitoring. Square represents average value and limit represents maximum

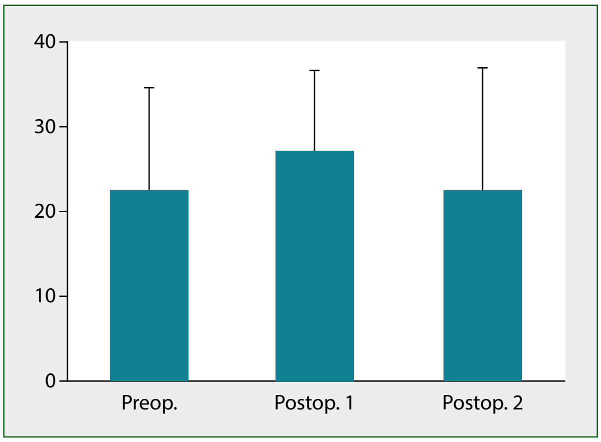

Figure 3. Distribution of cSVA values at three different time intervals. Postop. 1 means early postoperative monitoring, and postop. 2 means late postoperative monitoring. Square represents average value and limit represents maximum

Table 3. Freidman's ANOVA post hoc test results for lordosis angle C2-C7, showing differences in average rank values between individual pairs of variables

	SB C2-C7 preop.	SB C2-C7 postop. 1	SB C2-C7 postop. 2
SB C2-C7 preop.	—	0.25	0.59
SB C2-C7 postop. 1	0.25	—	**0.84**
SB C2-C7 postop. 2	0.59	**0.84**	—

SB — sagittal balance

Table 4. Freidman's ANOVA post hoc test results for cSVA, showing differences in mean rank values between individual pairs of variables

	cSVA preop.	cSVA postop. 1	cSVA postop. 2
cSVA preop.	—	**0.82**	0.00
cSVA postop. 1	**0.82**	—	**0.82**
cSVA postop. 2	0.00	**0.82**	—

Table 5. Pearson correlation coefficients between cSVA values measured at individual test stages

	cSVA preop.	cSVA postop. 1	cSVA postop. 2
cSVA preop.	1.00	**0.80**	**0.76**
cSVA postop. 1	**0.80**	1.00	**0.66**
cSVA postop. 2	**0.76**	**0.66**	0.00

late postoperative stage compared to the early monitoring (Fig. 3). Post hoc analysis showed that differences in cSVA measured in the preoperative phase and in the early postoperative monitoring were statistically significant. In addition, a significant difference in cSVA values occurred between the early and late postoperative stages (Tab. 4).

The cSVA values measured at each stage of the study were compared. Statistically significant, positive correlations were found between values obtained in the preoperative and early postoperative stages and the standard postoperative, as well as between early and standard postoperative stages (Tab. 5).

Discussion

The results obtained of C2-C7 lordosis angle variability before and after ACDF suggest that correction of the sagittal balance of the cervical spine is not associated with an intraoperative change in the morphology of spinal curvature potentially made by implantation of the stabilising system, and occurs within 38 months of observation.

In the literature, the cervical lordosis angle is given in the range of 20–40°, with up to 30% of healthy, adult people characterised by cervical kyphosis [26–31]. Benzel et al.

[32] showed that reduction, typical for osteoarthritis, in the height of the intervertebral disc is more strongly expressed in its abdominal area. As a consequence, greater loads are transferred through its front part, which may be responsible for the gradual loss of the lordotic cervical spine orientation observed in osteoarthritis [32]. This observation explains why, in the studied population of patients, preoperative values of the cervical lordosis angle were lower than the potential norm. This was confirmed by the studies of Chen et al. [2] and Gillis et al. [6] assessing the sagittal balance of the cervical spine in patients with cervical spondylosis, in which values similar to our study were obtained. Jackson et al. [33] and Hardacker et al. [28] proved that 75–80% of the cervical lordosis angle is formed by C1-C2 segments, with only 15% falling on C4-C7. This, in turn, explains the limited possibilities of absolute correction of the cervical lordosis angle by ACDF as the method intended for the treatment of pathology in C3-C7 segments.

There is a proven relationship between ACDF and an increase in the cervical lordosis angle or a decrease in the kyphosis angle [1–3, 5–10]. The same effect of ACDF on the setting of the segment subjected to spondylodesis has been demonstrated [1–3, 5, 6, 8].

Combining these two observations proves that primary correction of the sagittal balance within the segments operated on positively correlates with improvement of the position of the entire cervical spine [1, 6].

In this study, we have shown that correction of the sagittal balance of the cervical spine is not associated with an intraoperative change in the morphology of the curvature of the spine, and occurs during further observation. This conclusion is consistent with the observations of other authors. Gillis et al. [6] showed that the cervical lordosis angle C2-C7 increases by 12% in six weeks after ACDF and by another 18% over the next 12 months. Tomé-Bermejo et al. [5] observed that the cervical lordosis angle C1-C7 decreased by 4% in the 48 hours following ACDF, after which it increased by 18% in eight weeks and by another 4% over the next 12 months.

On the other hand, Chen et al. [2] showed that the cervical lordosis angle C2–C7 increases more than twice immediately after ACDF, after which it decreased by 23% systematically over 42 months of follow-up. However, contrary to the two previously mentioned studies, no statistical significance was demonstrated by Chen et al. [2]. This demonstrated lack of increase in the cervical lordosis angle immediately after implantation of the stabilising system is related to the observations of Villavicencio et al. [11], who found no effect of the use of lordotic interbody cages on the postoperative segmental and section lordosis angle.

In the available literature, results confirm the doubts arising from this study with regard to the shape of the implants used in ACDF on the correction of sagittal balance.

The results obtained of cSVA variation before and after ACDF suggest that the change in cSVA is associated with intraoperative correction of the cervical spine position by implantation of the stabilising system. Its further changes are a consequence of processes occurring during 38 months of observation.

Due to the small number of studies assessing cSVA, no norms have been set for this parameter. Gillis et al. [6] showed little variation after ACDF. According to their observation, six weeks after ACDF, cSVA increased by 9%, after which it decreased by 5% for the next 12 months. Similarly to the present study, this parameter increased early following ACDF, after which it decreased in further observation. In turn, Roguski et al. [14] demonstrated an 11% increase in cSVA one year after ACDF, and observed that pre- and postoperative cSVA values are an independent prognostic factor in treatment effectiveness. Most patients with cSVA > 40 mm achieved positive treatment effects only in terms of myelopathy symptoms. Patwardhan et al. [15], in a cadaver study, proved that the postoperative increase in biomechanical loads of adjacent to stabilisation levels increases with increasing cSVA.

It should therefore be assumed that the postoperative increase in cSVA is a negative effect, indicating a disturbance in the ratio of cervical curvature to the morphology of the entire spine. Gillis et al. [6] showed that cSVA positively correlates with the Th1 slope (T1S). Knott et al. [34] described T1S as a substitute parameter describing the sagittal balance of the cervical spine. Confirmed by this study and data obtained by Gillis et al. [6], the gradual return of cSVA to the baseline values before ACDF corresponds to the increase in the cervical lordosis angle observed at the same time.

Analysis of the relationship between cSVA values measured at various stages of the study proves a dependence between the degree of postoperative cervical spine curvature disorders and the morphology of the entire spine on their preoperative shaping.

It seems reasonable to assume that after ACDF there is a change in the biomechanics of the cervical spine, which in time leads to positive correction of the sagittal balance. This issue requires further research, which should first focus on the impact of ongoing spondylodesis, sagittal balance variability, muscle tone, and an ongoing degenerative process.

Kim et al. [17] showed that ACDF affects the correction of sagittal vertical axis, pelvic tilt, and sacral slope.

Therefore, future studies on postoperative variability of the sagittal balance after ACDF cannot be limited to assessing the morphology of the cervical spine only, and for a full understanding of the processes should include observations of whole body posture.

Part of the X-ray images assessed in this study did not show the Th1 circle. Consequently, it was impossible to perform measurements determining the parameters of the cervical-thoracic joint (thoracic inlet angle, neck tilt, T1 slope). Their examination would allow clinicians to refer changes in the sagittal balance of the cervical spine to the position of the thoracic part.

Conclusions

A long-term result of anterior cervical discectomy with fusion is correction of the sagittal balance of the cervical spine. This is not dependent only on the surgery itself, but also occurs in the postoperative period by increasing the lordosis angle. Immediately after the procedure, a disturbance in the cervical curvature to the morphology of the entire spine is observed by increasing the cervical sagittal vertical axis. This effect depends on their preoperative formation, and returns during observation.

A larger, prospective, and preferably multicentre, study should be conducted to confirm these conclusions.

Article information

Data availability statement: *The data that supports the findings of this study is available from the corresponding author, upon reasonable request.*

Ethics statement: *The study protocol was approved by the Ethics Committee of Pomeranian Medical University.*

Authors' contributions: *BL — main contribution; LS — review and guidelines; KL — review; WP — guidelines.*

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