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Changes in Cervical Sagittal Balance Following Anterior Cervical Discectomy with Fusion

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Abstract

Background: Changes in the sagittal balance after Anterior Cervical Discectomy with Fusion (ACDF) are phenomena that have not yet been sufficiently studied. The aim of this study is to assess these changes.

Methods: Twenty-eight patients who underwent ACDF for cervical spondylosis were examined. The study was divided into three stages: Preoperative, and early and late postoperative. Sagittal alignments were analyzed 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 differ significantly. 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 differ between preoperative and early postoperative monitoring and between early and late postoperative monitoring.

Conclusion: It has been shown that the long-term effect of ACDF is the 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

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Introduction

The most important publications about Sagittal Balance (SB) changes following surgical treatment of cervical spondylosis by Anterior Cervical Discectomy with Fusion (ACDF) are the achievements of the last few years [1-6].

The 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 been demonstrated [1-3,5,6,8]. Summarized conclusions allow one to put forward the hypothesis that the primary correction of the sagittal balance on the segments operated on positively correlates with the 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 with time [1-3,5,6]. In turn, 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 the 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 was shown that the degree of cervical lordosis angle improvement positively correlates with the length of stabilization [1,11]. 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 was observed [6,14]. In a cadaver study it was shown that the postoperative increase in biomechanical loads on the levels adjacent to stabilization increases 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.

The postoperative changes in cervical spine angles affect the effects of treatment. The relationship between lordosis correction and improvement in patients' condition has been proved [5,16,17]. In the case of cSVA, both pre- and post-operative values are an independent prognostic factor of treatment effectiveness. The majority of patients with cSVA >40 mm achieves positive treatment effects only in terms of myelopathy symptoms [14].

The effect of ACDF on the global sagittal balance of the spine was also observed. Decreased Sagittal Vertical Axis (SVA), increased Pelvic Tilt (PT) and decreased Sacral Slope (SS) were observed in patients with a large preoperative cervical lordosis angle [17].

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

Methods

Twenty-eight patients who underwent ACDF for cervical spondylosis at Department of Neurosurgery and Pediatric Neurosurgery at the Pomeranian Medical University in Szczecin from March 2012 to June 2013 were examined. 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 6 men. Their average age was 51 years (31-61, SD 7.69). All patients were operated on by one 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 day after surgery in 27 patients, the third (late postoperative) with routine outpatient follow-up, on average 38 months (11-46, SD 7.83), in 24 patients. Descriptive statistics for the age and time between study stages are presented in Table 1. The decreasing number of patients included in subsequent stages of the study resulted from the difficulty of continuing regular follow-up visits. Missing data were supplemented by substituting the arithmetic mean of individual parameters.

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 Aristos 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 respectively C2-C7, C4-C7. The widely recognized Cobb angle method was used to measure curvatures [19-23]. This method involves running four straight lines. Depending on the analyzed parts, horizontals run between the anterior and posterior C1 nodules, parallel to the lower endplate of C2, C4 or C7. Then vertical straight lines are perpendicular to the appropriate horizontal ones, and the angle formed by their intersection determines the value of 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-C2 plumb line), i.e., the vertical straight line passing through the center of the C2 body and the upper-posterior corner of the C7 body [6,14-16].

Lines giving and calculation of angles were made with the Surgimap program (Nemaris, Inc.) distributed with freeware license. The algorithms included in the program allow the precise and repeatable determination of spinal osteometric parameters [24,25].

Descriptive statistics were used in the statistical analysis, where the mean, standard deviation, minimum and maximum values were calculated. Arithmetic average method was used to fill in the missing data. The assumption about the normality of the distribution of quantitative variables was 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 ANOVY and post-hoc tests. Correlations were established using the Pearson linear correlation coefficient. The results were considered significant at $p<0.05$. The calculations were carried out with the Statistica 12 program (StatSoft).

Results

The average cervical lordosis angle C2-C7 was 11.62 ^{O} (-11.0-34.0; SD 12.73) preoperatively, 10.12 ^{O} (-12.0-24.0; SD 6.76) in early postoperative monitoring and 16.25 ^{O} (3.0-31.0; SD 7.84) in the late. C1-C7 values were 38.46 ^{O} (15.0-67.0; SD 12.85) respectively in the 1st stage of the study, 37.19 ^{O} (15.0-51.0; SD 7.70) in the 2nd stage and 41.79 ^{O} (12.0-63.0; SD 12.90) in the 3rd stage. C1-C2 were 26.12 ^{O} (15.0-36.0; SD 6.02) preoperatively, 27.12 ^{O} (15.0-41.0; SD 5.81) in early postoperative monitoring and 26.92 ^{O} (14.0-37.0, SD 6.08) in the late. C1-C4 were 29.73 ^{O} (13.0-47.0; SD 9.28) in the 1st stage, 26.96 ^{O} (-9.0-40.0; SD 10.46) in the 2nd stage and 28.46 ^{O} (-13.0-50.0; SD 12.37) in stage 3rd. C4-C7 were 8.23 ^{O} (-13.0-35.0; SD 10.69) preoperatively, 8.73 ^{O} (-2.0-19.0; SD 5.81) in early postoperative monitoring and 10.83 ^{O} (-2.0-35.0, SD 8.29) in the late. The average cSVA values were 22.00 mm (3.2-55.4; SD 10.08) in the 1st stage, 27.12 mm (9.5-41.5; SD 9.51) in the 2nd stage and 22.04 mm (5.4-48.9; SD 10.54) 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 presented in Table 2. Figure 1 is showing the reduction of the C2-C7 extension ROM.

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 early monitoring (Figure 2). The post-hoc analysis showed statistically significant differences in the value of the cervical lordosis angle between early and late postoperative monitoring (Table 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

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

Feature	mean	min	max	SD
Age (years)	51.29	31	61	7.69
Time (months)	37.71	11	46	7.83

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

Feature	mean	min	max	SD	p
SB C2-C7 preop. [°]	11.62	-11	34	12.73	0.014
SB C2-C7 postop. 1 [°]	10.12	-12	24	6.76	
SB C2-C7 postop. 2 [°]	16.25	3	31	7.84	
SB C1-C7 preop. [°]	38.46	15	67	12.85	0.285
SB C1-C7 postop. 1 [°]	37.19	15	51	7.7	
SB C1-C7 postop. 2 [°]	41.79	12	63	12.9	
SB C1-C2 preop. [°]	26.12	15	36	6.02	0.433
SB C1-C2 postop. 1 [°]	27.12	15	41	5.81	
SB C1-C2 postop. 2 [°]	26.92	14	37	6.08	
SB C1-C4 preop. [°]	29.73	13,0	47	9.28	0.953
SB C1-C4 postop. 1 [°]	26.96	-9	40	10.46	
SB C1-C4 postop. 2 [°]	28.46	-13	50	12.37	
SB C4-C7 preop. [°]	8.23	-13	35	10.69	0.272
SB C4-C7 postop. 1 [°]	8.73	-2	19	5.81	
SB C4-C7 postop. 2 [°]	10.83	-2	35	8.29	
cSVA preop. [mm]	22	3.2	45.4	10.08	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	

The differences in bold are statistically significant. Postop. 1 means early postoperative monitoring, and postop. 2, late.

Table 3: Friedman ANOVY 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	---

The differences in bold are statistically significant. Postop. 1 means early postoperative monitoring, and postop. 2, late.

Table 4: Friedman ANOVY 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	---

The differences in bold are statistically significant. Postop. 1 means early postoperative monitoring, and postop. 2 late.

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 late postoperative stage compared to early monitoring (Figure 3). Post-hoc analysis showed that statistically significant 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 stage (Table 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 standard postoperative, as well as between early and standard postoperative stages (Table 5).

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

The dependencies marked in bold are statistically significant. Postop. 1 means early postoperative monitoring, and postop. 2, late.

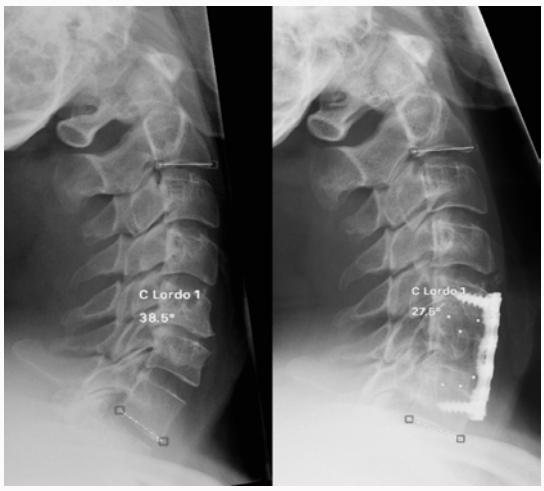

Figure 1: Dynamic, lateral, pre- and postoperative X-rays showing the reduction of the C2-C7 extension ROM after ACDF.

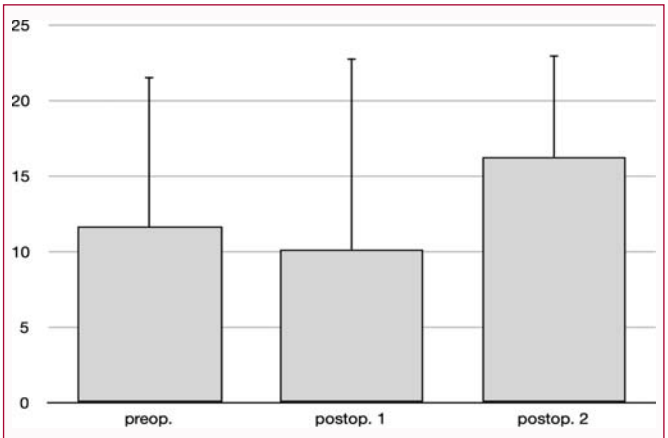

Figure 2: Distribution of C2-C7 lordosis angle values at three different time intervals. Postop. 1 means early postoperative monitoring, and postop. 2, late.

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 stabilizing 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 characterized by cervical kyphosis [26-31]. Benzel et al. 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

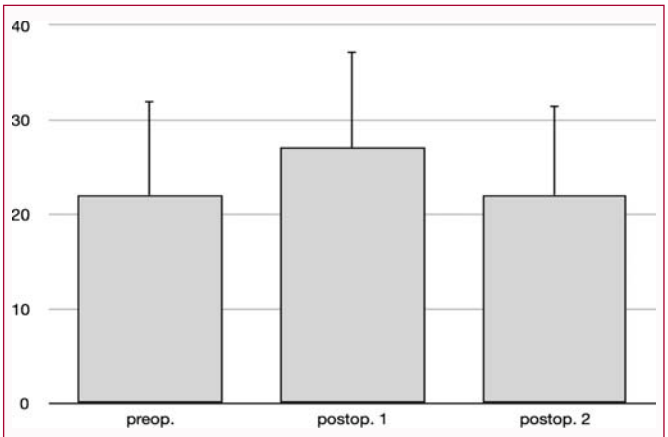

Figure 3: Distribution of cSVA values at three different time intervals. Postop. 1 means early postoperative monitoring, and postop. 2, late.

in osteoarthritis [32]. This observation explains why in the studied population of patients, preoperative values of the cervical lordosis angle are lower than the potential norm. This was confirmed by the studies of Chen et al. and Gillis et al. assessing the sagittal balance of the cervical spine in patients with cervical spondylosis, in which values similar to this study were obtained [2,6]. Jackson et al. and Hardacker et al. proved that 75% to 80% of the cervical lordosis angle is formed by C1-C2 segments, with only 15% falling on C4-C7 [28,33]. 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.

The relationship between ACDF and an increase in the cervical lordosis angle or a decrease in the kyphosis angle has been proved [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]. The combination of the above observations proves that the primary correction of the sagittal balance within the segments operated on positively correlates with the improvement of the position of the entire cervical spine [1,6].

In this study, it has been 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 some authors. Gillis et al. showed that the cervical lordosis angle C2-C7 increases by 12% in 6 weeks after ACDF and by another 18% over the next year [6]. Tomé-Bermejo et al. observed that the cervical lordosis angle C1-C7 decreased by 4% in 48 h following ACDF, after which it increased by 18% in 8 weeks and by another 4% for the next year [5]. On the other hand, Chen et al. 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 studies mentioned above, no statistical significance was demonstrated in this case [2]. This demonstrated lack of increase in the cervical lordosis angle immediately after implantation of the stabilizing system is related to the observations of Villavicencio et al. who found no effect of the use of lordotic interbody cages on the postoperative segmental and section lordosis angle [11]. In the available literature, results of research confirm the doubt 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 stabilizing 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. showed little variation after ACDF. According to their observation, after 6 weeks from ACDF cSVA increased by 9%, after which it decreased by 5% for the next year [6]. Similarly, to the present study, this parameter increased early following ACDF, after which it decreased in further observation. In turn, Roguski et al. demonstrated an 11% increase in cSVA one year after ACDF and observed that pre- and post-operative 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 [14]. Patwardhan et al. in a cadaver study proved that the postoperative increase in biomechanical loads of adjacent to stabilization levels increases with increasing cSVA [15]. 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. showed that cSVA positively correlates with the Th1 slope (T1 slope-T1S) [6]. Knott et al. described T1S as a substitute parameter describing the sagittal balance of the cervical spine [34]. Confirmed by this study and data obtained by Gillis et al., 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.

The analysis of the relationship between cSVA values measured at various stages of the study proves the dependence between the degrees of postoperative cervical spine curvature disorders to 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. showed that ACDF affects the correction of sagittal vertical axis, pelvic tilt and sacral slope [17].

Therefore, subsequent 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 observation of the 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 one to refer changes in the sagittal balance of the cervical spine to the position of the thoracic part.

Conclusion

A long-term result of anterior cervical discectomy with fusion is correction of the sagittal balance of the cervical spine. It is not dependent only on the surgery itself, but 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.

References

1. Oh JK, Kim TY, Lee HS, You NK, Choi GH, Yi S, et al. Stand-alone cervical cages versus anterior cervical plate in 2-level cervical anterior interbody fusion patients: clinical outcomes and radiologic changes. J Spinal Disord Tech. 2013;26(8):415-20.
2. Chen Y, Chen H, Cao P, Yuan W. Anterior cervical interbody fusion with the Zero-P spacer: Mid-term results of two-level fusion. Eur Spine J. 2015;24(8):1666-72.
3. Kim CH, Chung CK, Jahng TA, Park SB, Sohn S, Lee S. Segmental kyphosis after cervical interbody fusion with stand-alone Polyetheretherketone (PEEK) cages: A comparative study on 2 different PEEK cages. J Spinal Disord Tech. 2015;28(1):E17-24.
4. Le Huec JC, Faundez A, Dominguez D, Hoffmeyer P, Aunoble S. Evidence showing the relationship between sagittal balance and clinical outcomes in surgical treatment of degenerative spinal diseases: A literature review. Int Orthop. 2015;39(1):87-95.
5. Tomé-Bermejo F, Morales-Valencia JA, Moreno-Pérez J, Marfil-Pérez J, Díaz-Dominguez E, Piñera AR, et al. Long-term Changes in sagittal alignment and its clinical implications after cervical interbody fusion cage subsidence for degenerative cervical disc disease. A prospective study with standalone Lordotic Tantalum cages. Clin Spine Surg. 2017;30(5):E648-55.
6. Gillis CC, Kaszuba MC, Traynelis VC. Cervical radiographic parameters in 1- and 2-level anterior cervical discectomy and fusion. J Neurosurg Spine. 2016;35(4):421-9.
7. Uchida K, Nakajima H, Sato R, Yayama T, Mwaka ES, Kobayashi S, et al. Cervical spondylotic myelopathy associated with kyphosis or sagittal sigmoid alignment: Outcome after anterior or posterior decompression. J Neurosurg Spine. 2009;11(5):521-8.
8. Park DK, Lin EL, Phillips FM. Index and adjacent level kinematics after cervical disc replacement and anterior fusion: *In vivo* quantitative radiographic analysis. Spine (Phila Pa 1976). 2011;36(9):721-30.
9. Park SB, Jahng TA, Chung CK. Remodeling of adjacent spinal alignments following cervical arthroplasty and anterior discectomy and fusion. Eur Spine J. 2012;21(2):322-7.
10. Fujii K, Kawamura N, Ikegami M, Niitsuma G, Kunogi J. Radiological improvements in global sagittal alignment after lumbar decompression without fusion. Spine (Phila Pa 1976). 2015;40(10):703-9.
11. Villavicencio AT, Babuska JM, Ashton A, Busch E, Roeca C, Nelson EL, et al. Prospective, randomized, double-blind clinical study evaluating the correlation of clinical outcomes and cervical sagittal alignment. Neurosurgery. 2011;68(5):1309-16; discussion 1316.
12. Kim SW, Shin JH, Arbatin JJ, Park MS, Chung YK, McAfee PC. Effects of a cervical disc prosthesis on maintaining sagittal alignment of the functional spinal unit and overall sagittal balance of the cervical spine. Eur Spine J. 2008;17(1):20-9.
13. Lau D, Ziewacz JE, Le H, Wadhwa R, Mummaneni PV. A controlled anterior sequential interbody dilation technique for correction of cervical kyphosis. J Neurosurg Spine. 2015;23(3):263-73.
14. Roguski M, Benzel EC, Curran JN, Magge SN, Bisson EF, Krishnaney A. et al. Postoperative cervical sagittal imbalance negatively affects outcomes after surgery for cervical spondylotic myelopathy. Spine (Phila Pa 1976). 2014;39(25):2070-7.
15. Patwardhan AG, Khayatzadeh S, Nguyen NL, Havey RM, Voronov LI, Muriuki MG, et al. Is cervical sagittal imbalance a risk factor for adjacent segment pathomechanics after multilevel fusion? Spine (Phila Pa 1976). 2016;41(10):E580-8.
16. Tang JA, Scheer JK, Smith JS, Deviren V, Bess S, Hart RA, et al. The impact of standing regional cervical sagittal alignment on outcomes in posterior cervical fusion surgery. Neurosurgery. 2012;71(3):662-9.
17. Kim JH, Park JY, Yi S, Kim KH, Kuh SU, Chin DK, et al. Anterior cervical discectomy and fusion alters whole-spine sagittal alignment. Yonsei Med. 2015;56(4):1060-70.
18. Morvan G, Mathieu P, Vuillemin V, Guerini H, Bossard P, Zeitoun F, et al. Standardized way for imaging of the sagittal spinal balance. Eur Spine J. 2011;20(Suppl 5):602-8.
19. Cobb JR. Outlines for the study of scoliosis. In: Edwards, editor. The American academy of orthopedic surgeons instructional course lectures. Ann Arbor. 1948;5:261-75.
20. Singer KP, Jones TJ, Breidahl PD. A comparison of radiographic and computer-assisted measurements of thoracic and thoracolumbar sagittal curvature. Skeletal Radiol. 1990;19(1):21-6.
21. Polly DW, Kilkelly FX, McHale KA, Asplund LM, Mulligan M, Chang AS. Measurement of lumbar lordosis. Evaluation of intraobserver, interobserver, and technique variability. Spine. 1996;21(13):1530-5; discussion 1535-6.
22. Harrison DE, Harrison DD, Cailliet R, Troyanovich SJ, Janik TJ, Holland B. Cobb method or Harrison posterior tangent method: Which to choose for lateral cervical radiographic analysis. Spine (Phila Pa 1976). 2000;25(16):2072-8.
23. Srinivasalu S, Modi HN, Smehta S, Suh SW, Chen T, Murun T. Cobb angle measurement of scoliosis using computer measurement of digitally acquired radiographs-intraobserver and interobserver variability. Asian Spine J. 2008;2(2):90-3.
24. Akbar M, Terran J, Ames CP, Lafage V, Schwab F. Use of Surgimap Spine in sagittal plane analysis, osteotomy planning, and correction calculation. Neurosurg Clin N Am. 2013;24(2):163-72.
25. Lafage R, Ferrero E, Henry JK, Challier V, Diebo B, Liabaud B, et al. Validation of a new computer-assisted tool to measure spino-pelvic parameters. Spine J. 2015;15(12):2493-502.
26. Gore DR, Sepic SB, Gardner GM. Roentgenographic findings of the cervical spine in asymptomatic people. Spine (Phila Pa 1976). 1986;11(6):521-4.
27. Gay RE. The curve of the cervical spine: Variations and significance. J Manipulative Physiol Ther. 1993;16(9):591-4.
28. Hardacker JW, Shuford RF, Capicotto PN, Pryor PW. Radiographic standing cervical segmental alignment in adult volunteers without neck symptoms. Spine (Phila Pa 1976). 1997;22(13):1472-80.
29. Gore DR. Roentgenographic findings in the cervical spine in asymptomatic persons: A ten-year follow-up. Spine. 2001;26(22):2463-6.
30. Lee SH, Kim KT, Seo EM, Suk KS, Kwack YH, Son ES. The influence of thoracic inlet alignment on the craniocervical sagittal balance in asymptomatic adults. J Spinal Disord Tech. 2012;25(2):E41-7.
31. Le Huec JC, Demezon H, Aunoble S. Sagittal parameters of global cervical balance using EOS imaging: Normative values from a prospective cohort of asymptomatic volunteers. Eur Spine J. 2015;24(1):63-71.
32. Benzel EC, Kayanja M, Fleischman A, Roy S. Spine biomechanics: Fundamentals and future. Clin Neurosurg. 2006;53:98-105.
33. Jackson RP, McManus AC. Radiographic analysis of sagittal plane alignment and balance in standing volunteers and patients with low back pain matched for age, sex, and size. A prospective controlled clinical study. Spine (Phila Pa 1976). 1994;19(14):1611-8.
34. Knott PT, Mardjetko SM, Techy F. The use of the T1 sagittal angle in predicting overall sagittal balance of the spine. Spine J. 2010;10(11):994-8.