Cranial Center of Mass Compared to C7 Plumb Line Alignment in Adult Spinal Deformity

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■ OBJECTIVE: **To report the cranial center of mass (CCOM) progression in surgically treated patients for adult spinal deformity (ASD). The C7 plumb line/sagittal vertical axis (SVA) has important relationships with patient-reported outcomes; however, this has not yet been defined for CCOM.**

■ METHODS: **Patients with consecutive ASD who were undergoing surgery greater than 5 levels of fusion between 2007 and 2012 and had radiographic, clinical, and outcomes data spanning ≥2 years were analyzed, retrospectively. Radiographic parameters were obtained preoperatively and at 6 weeks, 1 year, and 2 years postoperatively. Statistical analysis included descriptives (measures of central tendency, dispersion, frequencies), independent Student *t* tests, χ^2 square, Pearson correlation, and Kaplan-Meyer curve.**

■ RESULTS: **Fifty-eight patients (10 male, 48 female) with a mean age of 60.5 years (range, 27–81 years) were reviewed. The mean preoperative SVA was 7.40 cm (SD = 5.51; 37/58 [63.8%] malalignment), and mean CCOM was 10.0 cm (SD = 6.58; 47/58 [81%] malalignment). Six-week postoperative SVA and CCOM was −0.17 cm (SD = 3.3) and 2.5 cm (SD = 4.11), respectively. SVA malalignment was 12.7% and CCOM malalignment was 38.2% at 6 weeks postop. Six week (absolute), 6-week change, and patient number at 6 weeks who were CCOM malaligned was significant compared with SVA ($P = 0.003$, $P < 0.001$, $P < 0.001$, respectively). SRS appearance worsened as preoperative SVA and CCOM increased ($P < 0.05$), and 2-year SRS appearance and mental health was worsened as 2-year SVA and CCOM increased ($P < 0.05$). SVA malalignment was 8 and 10 at 1 and 2 years, respectively, and CCOM malalignment was 24 and 32, respectively. Kaplan-Meier curve demonstrates persistent malalignment of CCOM at 6 weeks if not corrected.**

■ CONCLUSION: **CCOM alignment restoration is an important parameter in ASD, and malalignment is consistent over time.**

INTRODUCTION

Defining a normal distribution of alignment in the sagittal plane has focused mostly on the use of the C7 plumb line/sagittal vertical axis (SVA).[1-4] Sagittal alignment has important implications for energy expenditure and maintenance of posture.[5] Glassman et al.[4] identified the anterior displacement of the C7 plumb line as the radiographic parameter correlated with adverse patient-reported outcomes (PROs). In a prior study, we examined asymptomatic patients in 2 age groups (20–40-year-old patients and 60–80-year-old patients) and analyzed C7, C2, and cranial center of mass (CCOM) parameters. The findings suggested that the mean plumb lines are different between these age groups: C7 of −16.4 mm (SD = 31.5 mm) and 10.6 mm (SD = 27.8 mm), respectively, and CCOM of 9.0 mm (SD = 31.5 mm) and 41.2 mm (SD = 35.7 mm), respectively. Because normative values for C7 alignment and CCOM alignment in asymptomatic patients have been established, we wished to determine whether radiographic parameters correlated with adverse PROs after adult spinal deformity (ASD) surgery.

Key words
- Adult spinal deformity
- Cranial center of mass
- Patient-reported outcomes
- Sagittal vertical axis
- Scoliosis Research Society

Abbreviations and Acronyms
ASD: Adult spinal deformity
CCOM: Cranial center of mass
ODI: Oswestry Disability Index
PROs: Patient-reported outcomes
SRS: Scoliosis Research Society
SVA: Sagittal vertical axis

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Early literature has focused on identifying what constitutes overall spinal balance. Vital et al.[6] has examined the center of gravity, which we define as the CCOM, in 6 isolated formolized heads by a suspension method. Their work identified the center of gravity as the midpoint of the nasion-inion line.[6] A study by Tang et al.[5] demonstrated correlations between cervical sagittal malalignment and PROs after posterior cervical fusion.[5] Dubousset's "Cone of Economy" theory highlights the body's ability to adapt to changes in balance to regulate the center of gravity over a narrow perimeter.[7] He further references the postural alignment of the head over the feet and the minimum muscular energy required to maintain balance of these structures by allowing the pelvic unit to adapt.[7] This concept highlights the importance of the position of the head, and not solely the C7 vertebra. To our knowledge, no study has addressed the effects of the position of the cranium in relation to the sacrum in ASD surgery and evaluated it over a 2-year period. We hypothesize that the CCOM will progressively become more unbalanced after ASD surgery if not accounted for in the index procedure.

METHODS

After confirming institutional review board approval, a retrospective analysis of consecutive ASD patients undergoing elective surgery greater than 5 levels of fusion from a single institution between 2007 and 2012 was performed. All surgeries were performed by senior author TRK. The inpatient and outpatient medical records including radiographs were featured in the review. Inclusion criteria were as follows: 1) elective ASD surgery patients $\geq$5 levels; 2) fusions in the thoracic or lumbar spine, or both; 3) minimum 2-year follow-up with both complete radiographic evaluation and clinical follow-up. Exclusion criteria were as follows: 1) patients $<$ 18 years of age; 2) patients with neuromuscular or congenital scoliosis; 3) fusions in the cervical or cervicothoracic spine; 4) non-elective conditions (infection, tumor, trauma); 5) patients not meeting complete follow-up requirements.

Complete radiographic evaluation included preoperative, 6-week postoperative, 1-year postoperative, and 2-year standing, postoperative, long cassette plain films (14 $\times$ 36 inches). The cranium, femoral heads, and spinopelvic endplates had to be clearly visible for inclusion. If any anatomic landmarks on radiographs were poorly visible, they were excluded.

Radiographic Measurements

Radiographic parameters measured included primary and secondary Cobb angles in the coronal plane. Additional radiographic parameters were performed based on previously described definitions.[8] The SVA was measured as the distance from the C7 plumb line to the perpendicular line drawn from the posterior superior endplate of the S1 vertebral body. The C2 plumb line is a vertical plumb dropped from the center of the C2 vertebral body. The CCOM was a plumb line dropped from the midpoint of the nasion-inion line. The C2 plumb and the CCOM were measured in relation to the posterior superior endplate of S1. If the plumb line fell in front of the posterior superior endplate of S1, it was considered positive. If the plumb line fell behind the posterior superior endplate of S1, it was considered negative. Lumbar lordosis was measured from the upper endplate of T12 to the endplate of S1. Thoracic kyphosis was measured from the upper endplate of T5 to the lower endplate of T12. Pelvic incidence was measured from the angle subtended by a perpendicular from the cephalad endplate of S1 and a line connecting the center of the femoral heads to the center of the cephalad endplate of S1. Pelvic tilt was measured from the angle from a line drawn vertically from center of the femoral heads to the midpoint of the cephalad endplate of S1.

SVA and CCOM alignment were defined as $\pm$5 cm and $\pm$4 cm, respectively. A prior study showed an age-dependent CCOM parameter within $\pm$4 cm in asymptomatic volunteers.[1] The number of individuals outside these parameters for SVA and CCOM were recorded preoperatively, and at 6 weeks, 1 year, and 2 years postoperatively. We identified patients outside these parameters as malaligned.

Patient-Reported Outcomes

Scoliosis Research Society (SRS) 22 instrument domains and subscore and Oswestry Disability Index (ODI) were used to evaluate results of presurgical and postsurgical intervention. The relationships of these outcome measures with sagittal parameters were reported.

Statistical Analysis

Patient demographics and frequencies were reviewed. Descriptives included measures of central tendency, dispersion, and frequencies. SVA and CCOM were evaluated as both dichotomous and linear variables. Bivariate analysis included independent Student t tests, Pearson correlation, and χ^2. Kaplan-Meier curve was constructed for time-dependent analysis. Patient-reported outcomes were analyzed at each follow-up interval (6 week, 1 year, and 2 years) to determine the relationship with SVA and CCOM. All statistical analysis in this study was performed using SPSS version 22 (IBM, Armonk, New York, USA); $P < 0.05$ was considered statistically significant.

RESULTS

Fifty-eight patients (10 male, 48 female) with a mean age of 60.5 years (range, 27–81 years) who met complete radiographic and clinical follow-up criteria of minimum 2 years. These patients were analyzed, and the results are reflected in Table 1. All patients underwent surgical correction for ASD. Fifty-three patients

Table 1. Demographics for 58 Patients in Study

Age (mean, SD)	60.5 years	8.8
Sex (n, %)	48 female, 10 male	82.8%:17.2%
Iliac Fixation (n, %)	53	91.4%
Vertebroplasty (n, %)	20	34.5%
Hospital LOS (mean, SD)	301 hours	124

LOS, length of stay.