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The Importance of Incorporating Proportional Alignment in Adult Cervical Deformity Corrections Relative to Regional and Global Alignment

Steps Toward Development of a Cervical-Specific Score

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Study Design/Setting. Retrospective single-center study.

Background. The global alignment and proportion score is widely used in adult spinal deformity surgery. However, it is not specific to the parameters used in adult cervical deformity (ACD).

Purpose. Create a cervicothoracic alignment and proportion (CAP) score in patients with operative ACD.

Methods. Patients with ACD with 2-year data were included. Parameters consisted of relative McGregor's Slope [RMGS = (MGS × 1.5)/0.9], relative cervical lordosis [RCL = CL – thoracic kyphosis (TK)], Cervical Lordosis Distribution Index (CLDI = C2 – Apex × 100/C2 – T2), relative pelvic version (RPV = sacral slope – pelvic incidence × 0.59 + 9), and a frailty factor (greater than 0.33). Cutoff points were chosen where the cross-tabulation of parameter subgroups reached a maximal rate of meeting the Optimal Outcome. The optimal outcome was defined as meeting Good Clinical Outcome criteria without the occurrence of distal junctional failure (DJF) or reoperation. CAP was scored between 0 and 13 and categorized accordingly: ≤3 (proportioned), 4–6 (moderately disproportioned), >6 (severely disproportioned). Multivariable logistic regression analysis determined the relationship between CAP categories, overall score, and development of distal junctional kyphosis (DJK), DJF, reoperation, and Optimal Outcome by 2 years.

Results. One hundred five patients with operative ACD were included. Assessment of the 3-month CAP score found a mean of 5.2/13 possible points. 22.7% of patients were proportioned, 49.5% moderately disproportioned, and 27.8% severely disproportioned. DJK occurred in 34.5% and DJF in 8.7%, 20.0% underwent reoperation, and 55.7% achieved Optimal Outcome. Patients severely disproportioned in CAP had higher odds of DJK [OR: 6.0 (2.1–17.7); $P=0.001$], DJF [OR: 9.7 (1.8–51.8); $P=0.008$], reoperation [OR: 3.3 (1.9–10.6); $P=0.011$], and lower odds of meeting the optimal outcome [OR: 0.3 (0.1–0.7); $P=0.007$] by 2 years, while proportioned patients suffered zero occurrences of DJK or DJF.

Conclusion. The regional alignment and proportion score is a method of analyzing the cervical spine relative to global alignment and demonstrates the importance of maintaining horizontal gaze,

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while also matching overall cervical and thoracolumbar alignment to limit complications and maximize clinical improvement.

Key words: regional alignment, cervical deformity, proportion, GAP, CAP, DJK

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Adult cervical deformity (ACD) is a potentially debilitating disorder that can pathologically alter posture and may be associated with significant pain, neurological injury, and disability.[1,2] More so, previous studies have demonstrated that cervical deformity has a more detrimental impact on quality of life than other significant conditions like blindness and metastatic cancer.[3] Correction of cervical malalignment has been shown to significantly benefit patients with ACD by restoring horizontal gaze and improving functionality.[4,5] Corrective procedures are often conducted in patients with severe frailty and concurrent osteoporosis, who are inherently susceptible to complications including pseudarthrosis, distal junctional kyphosis (DJK), and distal junctional failure (DJF).[6–10]

The challenge in this context is balancing the invasiveness necessary for optimal correction against the potential for postsurgical complications and construct failure, and there are limited indices available to guide decision-making, especially within ACD. Recently, Yilgor *et al*[11] proposed the global alignment and proportion (GAP) score, which utilizes pelvic incidence-based parameters to predict mechanical complications in patients with adult spinal deformity. The GAP score comprises individual scores for relative lumbar lordosis, lordosis distribution index, relative spino-pelvic alignment, relative pelvic version (RPV), and an age factor, with a total score ranging from 0 to 13 points. While the GAP score has gained popularity in a number of respects, its utility has proven inconsistent in validation studies and the parameters incorporated are not specific to patients with cervical deformity.[12]

In this context, we sought to create a cervicothoracic[13] alignment and proportion (CAP) score for patients with operative ACD correlating to both clinical improvement and complications within 2 years postoperatively. We hypothesize that the incorporation of patient-specific targets would better aid in predicting clinically relevant outcomes.

TABLE 1. Definitions of Two-Year Outcomes

Clinical outcome	Two-year definition
MCID in mJOA	Improvement ≥1.8
MCID in NDI	Improvement ≥15
MCID in NRS-Neck	Improvement ≥2.5
Good Clinical Outcome	Meeting any two of the three criteria: (1) an NDI score less than 20 or meeting MCID in NDI (2) mild myelopathy (mJOA score equal to or greater than 14) (3) an NRS-Neck score less than or equal to 5 or improved by 2 or more points from baseline
Optimal Outcome	Meeting all four criteria: (1) Meeting Good Clinical Outcome (2) No occurrence of DJF (3) No occurrence of mechanical complications (4) No reoperation

DJF indicates distal junctional failure; MCID, minimally clinically important difference; mJOA, modified Japanese Orthopaedic Association; NDI, Neck Disability Index; NRS, Numerical Rating Scale.

MATERIALS AND METHODS

Study Inclusion Criteria

Consecutive adult patients (≥18 y) with ACD undergoing cervical fusion at a single center were included. ACD criteria were C2–7 Cobb angle >10°, coronal Cobb angle >10°,

TABLE 2. Cohort Demographics, Radiographics, and Surgical Details

Baseline demographics	
Age	57.6 ± 10.0 y
Gender	60% F
BMI (kg/m^2)	28.7 ± 7.1
CCI	0.9 ± 1.2
Frailty	0.25 ± 0.13
Previous cervical fusion (%)	24
Previous thoracolumbar fusion (%)	24
Surgical details	
EBL (mL)	791
Operative time (min)	393
Number of levels fused	8.0 ± 3.4 levels
Surgical approach (%)	Anterior: 14.7, posterior: 46.1, combined: 39.2
Length of stay (d)	4.6 ± 3.0
Radiographic parameters	
TS-CL (°)	38.0 ± 19.9
C2-C7 Lordosis (°)	–4.6 ± 22.3
C2-slope (°)	36.9 ± 18.8
T1-slope (°)	28.3 ± 14.5
cSVA (mm)	47.1 ± 25.2
McGregor Slope (°)	−2.7 ± 11.3
Baseline HRQLs	
EQ5D VAS	59.2
NDI	55.3
NRS Neck	7.4
mJOA score	13.0

BMI indicates body mass index; cSVA, C2–C7 sagittal vertical axis; CCI, Charlson Comorbidity Index; EBL, estimated blood loss; EQ5D VAS, EuroQOL 5-Dimension Questionnaire Visual Analog Scale; HRQL, health-related quality of life; mJOA, modified Japanese Orthopaedic Association; NDI, Neck Disability Index; NRS, Numerical Rating Scale; TS-CL, mismatch between T1 slope and cervical lordosis.

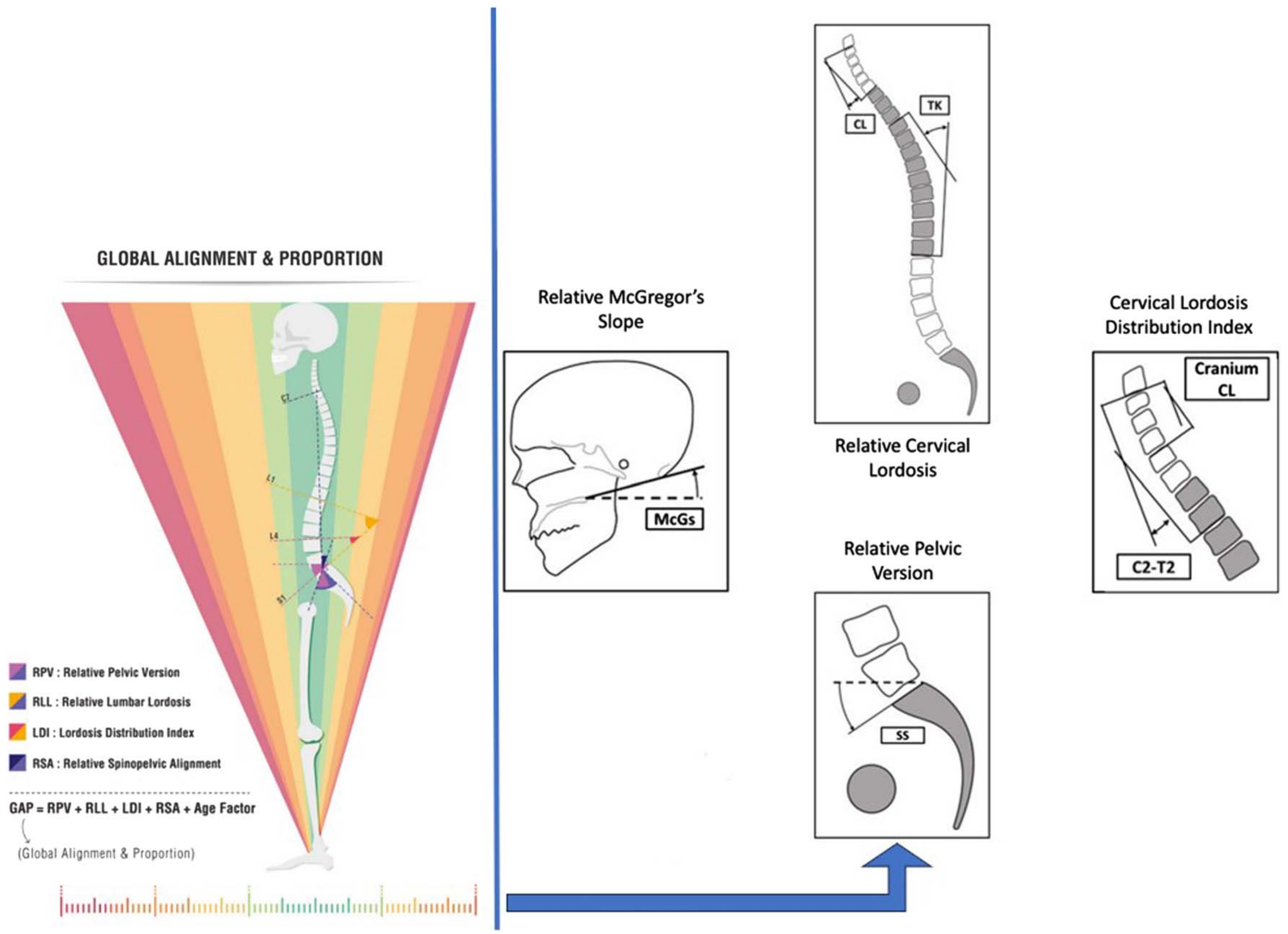

Figure 1. Depiction of the four parameters incorporated into the CAP score (relative cervical lordosis, McGregor's slope, cervical lordosis distribution index, and relative pelvic version). CAP, indicates cervicothoracic alignment and proportion; CL, cervical lordosis; TK, thoracic kyphosis. full color online

C2–C7 sagittal vertical axis (cSVA) >4 cm, the mismatch between T1 slope and cervical lordosis >10°, or chin-brow vertical angle >25°. Database inclusion criteria, as previously published, required the upper-instrumented vertebra of the fusion construct above the level of C7 and evidence of ACD on radiographic imaging.[14,15] Patient consent and Institutional Review Board (IRB) approval were obtained at the home institution before enrolling patients and each patient gave informed consent before surgery. Patients included had complete postoperative radiographic and 2-year health-related quality of life (HRQL) data.

Data Collection

Demographic data were collected at preoperative visit within 6 weeks of index surgery, including age, gender, body mass index, the modified cervical deformity frailty index by Passias *et al*, history of prior cervical fusion, and the Charlson Comorbidity Index.[8] Surgical data collected included the number of levels fused, estimated blood loss, operative time, surgical approach, decompression, and osteotomy type, as well as the length of stay, admission to the surgical intensive care unit, and disposition status upon discharge. Complication assessments were made based on a review of imaging, patient reports, and clinical follow-up. Clinical outcomes including neck disability [as assessed by the Neck Disability Index, EuroQOL 5-Dimension Questionnaire Visual Analog Scale, pain Numerical Rating Scale for both neck (NRS-neck) and back (NRS-back)] and myelopathy score (as assessed by the modified Japanese Orthopaedic Association) were obtained via patient surveys at baseline and follow-up at 3 months, 6 months, 1 year, and 2 years.

Radiographic Evaluation

Baseline and up to 2-year postoperative radiographs were evaluated using validated software programming (SpineView; ENSAM Laboratory of Biomechanics, Paris, France).[16–18] Cervical sagittal alignment and balance were evaluated using C2–C7 Cobb angle for cervical lordosis (CL: angle between the lower endplates of C2 and C7), C2 slope, T1 slope, C2–T2 Cobb angle, McGregor's slope (MGS), cSVA (C2 plumbline offset from the postero-superior corner of C7), the mismatch between T1 slope and CL, and the cervical apex of lordosis. Global sagittal alignment was assessed via the C7–S1 sagittal vertical axis, the mismatch between pelvic incidence and lumbar lordosis, and pelvic tilt.

Assessment of DJK and Failure

DJK, per previous literature, was defined per physician note or radiographically as DJK angle [kyphosis between the superior endplate of the lowest instrumented vertebra (LIV) and the inferior endplate of the second distal vertebra (LIV-2)] <–10°, and a preoperative to postoperative change in DJK angle <–10°.[19] Severe DJK, also known as DJF, was defined as DJK angle <–20° and postoperative change of <–20° from the presumed baseline LIV-2, or DJK leading to reoperation.

TABLE 3. χ^2 Values of Achieving Optimal Outcome Between CAP Parameter Categories

CAP parameter categories	Optimal outcome (%)	χ^2, *P*
Relative McGregor's Slope subgroups		
Upward neck tilt	44.4	15.848; *P* = 0.001
Neutral and erect	57.9	
Moderate downward tilt	14.3	
Severe downward tilt	11.1	
Relative cervical lordosis		
Moderately malaligned	39.1	6.310; *P* = 0.097
Mildly malaligned	44.4	
Aligned	48.3	
Severely malaligned	27.6	
Cervical Lordosis Distribution Index		
Hypolordotic	13.3	8.851; *P* = 0.031
Aligned	55.6	
Moderately hyperlordotic	51.0	
Severely hyperlordotic	32.5	
Relative pelvic version		
Severe retroversion	42.9	0.679; *P* = 0.878
Moderate retroversion	45.0	
Aligned	55.0	
Anteversion	52.9	
Frailty		
Not frail	55.4	1.165; *P* = 0.280
Frail	44.7	

CAP indicates cervicothoracic alignment and proportion.

TABLE 4. The CAP Score: The Parameters and Their Subgroups

Scoring			Scoring
Relative McGregor's Slope subgroups			Total score: 0–3 Proportioned
< −7.8	Upward neck tilt	+1	
−7.8 to 1	Neutral and erect	+0	
1 to 16.2	Moderate downward tilt	+2	
> 16.2	Severe downward tilt	+3	
Relative cervical lordosis			
< 35	Moderately malaligned	+2	
35–44	Mildly malaligned	+1	
44–68	Aligned	+0	
> 68	Severely malaligned	+3	
Cervical lordosis distribution index			Total score: 4–6 Moderately disproportioned
< 70	Hypolordotic	+3	
70–90	Aligned	+0	
90–150	Moderately hyperlordotic	+1	
> 150	Severely hyperlordotic	+3	
Relative pelvic version			Total score: > 6 Severely disproportioned
< −15	Severe retroversion	+3	
−15 to −7.1	Moderate retroversion	+2	
−7 to 5	Aligned	+0	
> 5	Anteversion	+1	
Frailty subgroups			
mCD-FI < 0.33	Not frail	+0	
mCD-FI ≥ 0.33	Frail	+1	

Scoring system is in the right-hand column.

CAP indicates cervicothoracic alignment and proportion; mCD-FI, modified cervical deformity frailty index.

Definition of Clinical Outcomes

The previously published minimally clinically important differences for the modified Japanese Orthopaedic Association, the Neck Disability Index, and NRS-Neck, the "Good Clinical Outcome" criteria, and our study-specific definition of *Optimal Outcome* are outlined and defined in Table 1.[14,20–22]

Statistical Analysis

Patient demographics were compared using means comparison and χ^2 analyses. χ^2 test was performed to compare the

TABLE 5. Health-related Quality of Life Outcomes and Complications Across CAP Categories

	Proportioned (%)	Moderately disproportioned (%)	Severely disproportioned (%)	P
Health-related quality of life outcomes				
Optimal Outcome	63.6	64.6	33.3	0.022
Complication outcomes				
Reoperation	13.6	14.6	29.6	0.223
DJK	0.0	29.0	59.1	< 0.001
DJF	0.0	4.2	22.2	0.006

CAP indicates cervicothoracic alignment and proportion; DJF, distal junctional failure; DJK, distal junctional kyphosis.

frequencies of mechanical complications in parameter subgroups. Statistical analyses were performed to determine correlations between HRQLs and possible modifiers. Radiographic parameters of interest were assessed via Pearson correlation, and optimal cutoff points for the CAP categories were identified using both theoretical and clinical justification and statistical analyses.[23] The cutoff points were chosen where the cross-tabulation of parameter subgroups *versus* achieving Optimal Outcome criteria by 2 years reached maximal χ^2 values.[11] Differences in HRQL scores between CAP and GAP categories were analyzed using analysis of covariance accounting for age, baseline deformity, Charlson Comorbidity Index, number of levels fused, and the use of a three-column osteotomy. Multivariable logistic regression analysis determined the relationship between CAP categories, the overall score, and the development of DJK, DJF, reoperation, and HRQL outcomes by 2 years. In all testing, significance was established *a priori* for odds ratios and 95% CIs exclusive of 1.0 and $P < 0.05$. All statistical analyses were conducted using SPSS, version 28.1.1 (Armonk, NY).

RESULTS

Demographic and Surgical Data

One hundred and five patients with ACD met inclusion criteria [mean (range) of follow-up: 2.7 years (2.0–4.6)]. The average age of the cohort was 57.6 ± 10.0 years and 60% of patients were female (Table 2). Most patients underwent a posterior-only approach (46.1%; n = 48), followed by a combined (39.2%; n = 41) or anterior-only approach (14.7%; n = 16). The mean total number of levels fused for the cohort was 8.0 ± 3.4, the mean operative time was 393 ± 336 minutes, and the mean estimated blood loss was 791 ± 846 mL. Baseline cervical and global alignment are seen in Table 2.

Development of the CAP Score

McGregor's slope, CL-TK, and C2–T2 angle relative to the cervical apex were incorporated into the CAP score which, similar to the original pelvic incidence-based GAP score, quantifies aspects of cervical proportionality using three cervical-specific factors [horizontal gaze (McGregor's), cervical lordosis relative to thoracic alignment (CL-TK), and lordosis distribution relative to the apex (cervical lordosis distribution index, CLDI)], along with one factor maintained from the original GAP score to account for lumbopelvic alignment (RPV) and a frailty factor (Fig. 1). C2–T2 was used instead of C2–C7 lordosis as studies have shown the cervicothoracic inflection point may actually lie near T2.[24]

Development of the CAP Score Categorical Thresholds

Relative McGregor's Slope [(MGS × 1.5)/0.9]

This parameter indicates the spatial orientation of the head relative to horizontal. Relative MGS of less than –7.8° was considered upward neck tilt; –7.8° to 1°, neutral and erect; 1° to 16.2°, moderate downward tilt; and > 16.2°, severe downward tilt.

Relative cervical lordosis (RCL) was derived from a paper by Lafage and colleagues, who determined that lumbar lordosis and thoracic kyphosis are interrelated. Therefore, given the compensatory mechanisms a spine undergoes to account

TABLE 6. Health-related Quality of Life Outcomes and Complications Across GAP Categories

	Proportioned (%)	Moderately disproportioned (%)	Severely disproportioned (%)	P
Health-related quality of life outcomes				
Optimal Outcome	55.4	63.6	60.0	0.747
Complication outcomes				
Reoperation	8.9	12.1	13.3	0.837
DJK	21.4	24.2	31.8	0.639
DJF	3.4	9.1	13.7	0.289

DJF indicates distal junctional failure; DJK, distal junctional kyphosis; GAP, global alignment and proportion.

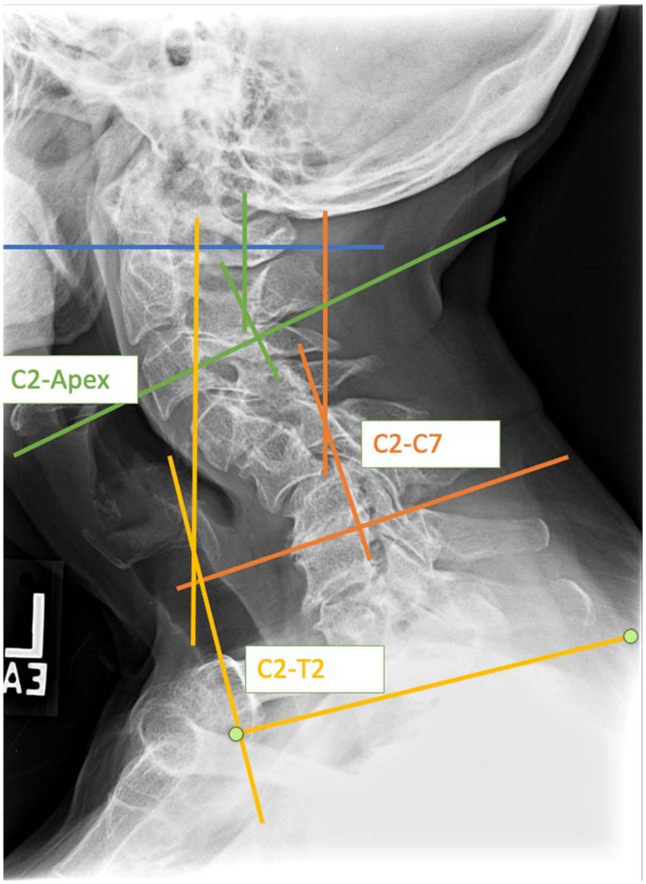

Figure 2. Preoperative and postoperative films of a 72-year-old female with severe focal deformity and kyphosis, most notably within the apex-T2 region resulting in a severely disproportionate CLDI as depicted in the figure, who underwent a combined anterior-posterior C3–T1 fusion with multiple facet osteotomies corrected from a preoperative CAP score of 11 (severely disproportioned) to a postoperative CAP score of 7 (severely disproportioned). At 6 years postoperatively, this patient developed severe distal junctional kyphosis requiring revision and extension of the cervicothoracic fusion, as well as a thoracolumbar fusion later in the postoperative period. CAP indicates cervicothoracic alignment and proportion; CLDI, Cervical Lordosis Distribution Index. full color online

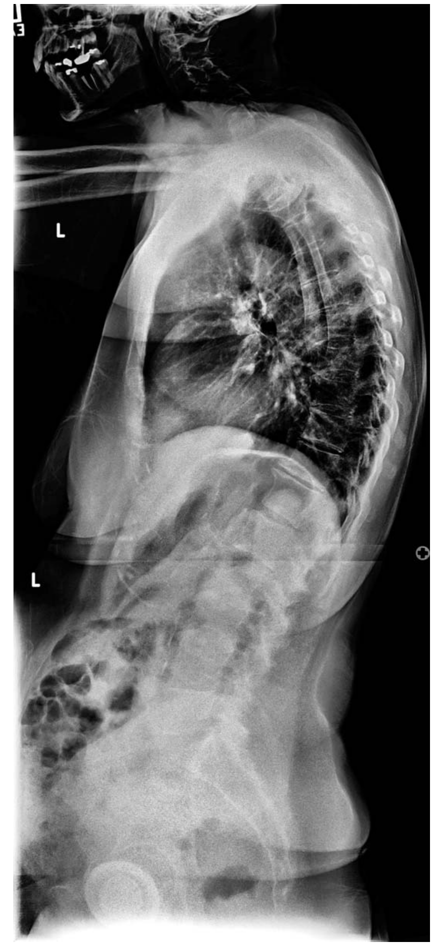

Figure 3. Preoperative and postoperative films of a 72-year-old female with severe focal deformity and kyphosis, most notably within the apex-T2 region resulting in a severely disproportionate CLDI as depicted in the figure, who underwent a combined anterior-posterior C3–T1 fusion with multiple facet osteotomies corrected from a preoperative CAP score of 11 (severely disproportioned) to a postoperative CAP score of 7 (severely disproportioned). At 6 years postoperatively, this patient developed severe distal junctional kyphosis requiring revision and extension of the cervicothoracic fusion, as well as a thoracolumbar fusion later in the postoperative period. CAP indicates cervicothoracic alignment and proportion; CLDI, Cervical Lordosis Distribution Index.

for deformity, we examined the relationship between cervical lordosis and thoracic kyphosis. RCL (cervical lordosis minus thoracic kyphosis): less than 35° was considered moderately malaligned; 35°–44°, mildly malaligned; 44°–68°, aligned; and >68°, severely malaligned.

CLDI (C2-Apex Divided by C2–T2 Lordosis Multiplied by 100)

This defines the amount of upper arc lordosis in proportion to the total cervical lordosis. The cervical apex of lordosis (transition of vertebral endplate slope from positive to negative within the cervical spine, also the vertebral body at the apex of the cervical lordosis) was chosen to provide a more patient-specific measure for the lordosis distribution, rather than using a standard segment for each patient (*e.g.*, C5–C7/C2–C7). T2 was chosen as the distal end of lordosis as previous studies have defined this as a transition point for lordosis to kyphosis as opposed to C7.[24] A CLDI of <70% was considered hypolordotic maldistribution; 70%–90%, aligned; 90%–150%, moderately hyperlordotic maldistribution; and >150%, severely hyperlordotic maldistribution.

RPV (Measured Sacral Slope Minus Pelvic Incidence × 0.59 + 9)

This parameter indicates the spatial orientation of the pelvis relative to the ideal sacral slope as defined by the magnitude of the pelvic incidence.[11] RPV of less than −15° was considered severe retroversion; −15° to −7.1°, moderate retroversion; −7° to 5°, aligned; and >5°, anteversion.

Figure 4. Preoperative and postoperative films of a 72-year-old female with severe focal deformity and kyphosis, most notably within the apex-T2 region resulting in a severely disproportionate CLDI as depicted in the figure, who underwent a combined anterior-posterior C3–T1 fusion with multiple facet osteotomies corrected from a preoperative CAP score of 11 (severely disproportioned) to a postoperative CAP score of 7 (severely disproportioned). At 6 years postoperatively, this patient developed severe distal junctional kyphosis requiring revision and extension of the cervicothoracic fusion, as well as a thoracolumbar fusion later in the postoperative period. CAP indicates cervicothoracic alignment and proportion; CLDI, Cervical Lordosis Distribution Index.

Figure 5. Preoperative and postoperative films of a 72-year-old female with severe focal deformity and kyphosis, most notably within the apex-T2 region resulting in a severely disproportionate CLDI as depicted in the figure, who underwent a combined anterior-posterior C3–T1 fusion with multiple facet osteotomies corrected from a preoperative CAP score of 11 (severely disproportioned) to a postoperative CAP score of 7 (severely disproportioned). At 6 years postoperatively, this patient developed severe distal junctional kyphosis requiring revision and extension of the cervicothoracic fusion, as well as a thoracolumbar fusion later in the postoperative period. CAP indicates cervicothoracic alignment and proportion; CLDI, Cervical Lordosis Distribution Index.

Frailty Factor

Frailty was stratified by the modified cervical deformity frailty index into two subgroups as <0.33 [Not Frail] and ≥ 0.33 [Frail].

The distribution of rates of Optimal Outcomes within parameter subgroups is tabulated in Table 3.

Calculation of the Total Score

The CAP score, calculated by adding the individual scores for relative MGS, RPV, RCL, CLDI, and the age factor, ranges from 0 to 13 points. Assessment of the 3-month CAP score in the present cohort found a mean of 5.2/13 possible points, as seen in Table 4. Patients were categorized accordingly: ≤ 3, proportioned; 4–6, moderately disproportioned; > 6 severely disproportioned. This categorized patients into the following CAP categories: 23% were proportioned, 49% moderately disproportioned, and 28% severely disproportioned.

Outcomes of Cohort

In regards to complications, 27.5% of patients developed DJK, 8.2% developed DJF, and 12.6% underwent reoperation. In addition, 53.9% of the cohort met the Good Clinical Outcome criteria, qualifying 46.7% of patients as meeting Optimal Outcome criteria at 2 years.

Performance of the Continuous CAP Score

Adjusted analysis controlling for age, revision status, number of levels fused, baseline deformity in C2–C7, and cSVA assessed for associations between the continuous postoperative CAP scores and either development of

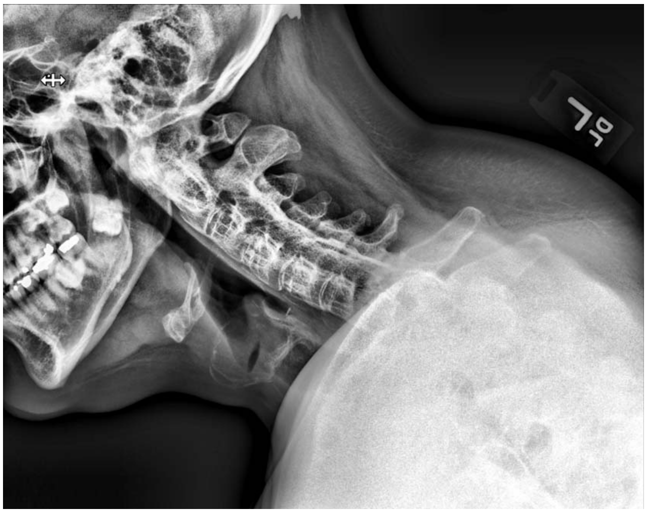

Figure 6. Preoperative and postoperative films of a 38-year-old male with severe global kyphosis and a cervicothoracic deformity, who underwent a posterior C2–T10 fusion with multiple facet osteotomies, and vertebral column resection in upper thoracic spine. Correction from a preoperative CAP score of 10 (severely disproportioned) to a postoperative CAP score of 3 (proportioned). At 2 years postoperatively, this patient has suffered no radiographic complications or undergone any additional spinal procedures. CAP indicates cervicothoracic alignment and proportion.

complications or rates of meeting Optimal Outcome. For an increasing CAP score, there was increased likelihood of developing DJK [OR: 1.2, 95% CI: (1.0–1.5); $P=0.039$], DJF [OR: 1.5, 95% CI: (1.1–2.0); $P=0.026$] and less odds of meeting Optimal Outcome [OR: 0.8, 95% CI: (0.71.0); $P=0.041$], but not undergoing reoperation [OR: 1.2, 95% CI: (0.9–1.6); $P=0.167$].

CAP and Postoperative Outcomes

Adjusted analysis controlling for age, revision status, number of levels fused, baseline deformity in C2–C7, and cSVA revealed patients severely disproportioned in CAP score had higher odds of DJK [OR: 6.0, 95% CI: (2.1–17.7), $P=0.001$], DJF [OR: 9.7, 95% CI: (1.8–51.8), $P=0.008$], and reoperation [OR: 3.9, 95% CI: (1.9–10.6), $P=0.011$], and less odds of meeting the Optimal Outcome [OR: 0.3, 95% CI: (0.1–0.7), $P=0.007$]. Patients proportioned in CAP score endured a rate of 0% for DJK (Table 5). When compared with the GAP score, neither the GAP score nor the individual GAP subparameters demonstrated differences between categories for DJK, DJF, or Optimal Outcome (all $P>0.2$; Table 6).

Case Examples

Preoperative and postoperative films of a 72-year-old female with severe kyphosis, who underwent a combined anterior-posterior C3–T1 fusion with multiple facet osteotomies corrected from a preoperative CAP score of 11 (severely disproportioned) to a postoperative CAP score of 7 (severely disproportioned) (Figures 2–5). At 6 years postoperatively, this patient developed severe DJK

Figure 7. Preoperative and postoperative films of a 38-year-old male with severe global kyphosis and a cervicothoracic deformity, who underwent a posterior C2–T10 fusion with multiple facet osteotomies, and vertebral column resection in upper thoracic spine. Correction from a preoperative CAP score of 10 (severely disproportioned) to a postoperative CAP score of 3 (proportioned). At 2 years postoperatively, this patient has suffered no radiographic complications or undergone any additional spinal procedures. CAP indicates cervicothoracic alignment and proportion.

requiring revision and extension of the cervicothoracic fusion, as well as a thoracolumbar fusion later in the postoperative period.

Preoperative and postoperative films of a 63-year-old female with severe global kyphosis, who underwent a combined anterior-posterior C2-T12 fusion with multiple facet osteotomies and pedicle subtraction osteotomy at T2 corrected from a preoperative CAP score of 10 (severely disproportioned) to a postoperative CAP score of 3 (proportioned) (Figures 6–11). At 5 years postoperatively, this patient has suffered no radiographic complications or undergone any additional spinal procedures.

DISCUSSION

While advancements in surgical technology and technique allow patients with operative ACD to experience

Figure 8. Preoperative and postoperative films of a 38-year-old male with severe global kyphosis and a cervicothoracic deformity, who underwent a posterior C2–T10 fusion with multiple facet osteotomies, and vertebral column resection in upper thoracic spine. Correction from a preoperative CAP score of 10 (severely disproportioned) to a postoperative CAP score of 3 (proportioned). At 2 years post-operatively, this patient has suffered no radiographic complications or undergone any additional spinal procedures. CAP indicates cervicothoracic alignment and proportion.

Figure 9. Preoperative and postoperative films of a 38-year-old male with severe global kyphosis and a cervicothoracic deformity, who underwent a posterior C2–T10 fusion with multiple facet osteotomies, and vertebral column resection in upper thoracic spine. Correction from a preoperative CAP score of 10 (severely disproportioned) to a postoperative CAP score of 3 (proportioned). At 2 years post-operatively, this patient has suffered no radiographic complications or undergone any additional spinal procedures. CAP indicates cervicothoracic alignment and proportion.

substantial clinical improvement, the reported rates of structural complications and revision remain high.[25–27] DJK and DJF in particular are prevalent, with rates upward of 27%.[26,28] However, the prediction of these occurrences is limited due to the heterogeneity of ACD cases, the complexity of etiology, and the lack of consensus regarding radiographic classifications. In addition, studies have shown that not all radiographic DJK hinders clinical improvement, whereas the more clinically relevant form, known as DJF, represents a more concerning instance and should be the primary target for mitigation.

Within the present study, the derivation of the CAP score isolated patients severely disproportioned and found significant associations with DJK, DJF, reoperations, and minimal clinical improvement in this group. In addition, those corrected to a proportioned state did not suffer any DJK or DJF, while also experiencing lower reoperation rates and substantial clinical utility from cervical deformity correction with better correlation to outcomes than the original GAP score.

In light of the GAP score, we intended to take a similar approach and derive a score specific to the cervical spine.[11] While the GAP score seeks to characterize the proportionment throughout the spine, this score does not have cervical-specific parameters and we found this score did not correlate with outcomes following cervical deformity correction. The CAP score describes the magnitude and distribution of ideal cervical alignment via score components such as the RCL and CLDI. The lordosis distribution index provides an individualized parameter as it incorporates the apex of lordosis into account, given the variability in its presentation.[24]

The third score component, relative McGregor's slope (RMGS), was chosen to represent the extent of malalignment in relation to horizontal gaze, a measure directly related to quality of life and functionality in patients with

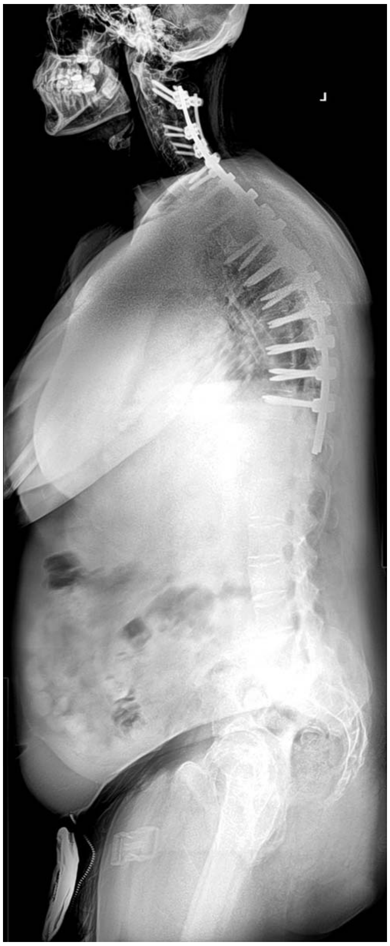

Figure 10. Preoperative and postoperative films of a 38-year-old male with severe global kyphosis and a cervicothoracic deformity, who underwent a posterior C2–T10 fusion with multiple facet osteotomies, and vertebral column resection in upper thoracic spine. Correction from a preoperative CAP score of 10 (severely disproportioned) to a postoperative CAP score of 3 (proportioned). At 2 years postoperatively, this patient has suffered no radiographic complications or undergone any additional spinal procedures. CAP indicates cervicothoracic alignment and proportion.

Figure 11. Preoperative and postoperative films of a 38-year-old male with severe global kyphosis and a cervicothoracic deformity, who underwent a posterior C2–T10 fusion with multiple facet osteotomies, and vertebral column resection in upper thoracic spine. Correction from a preoperative CAP score of 10 (severely disproportioned) to a postoperative CAP score of 3 (proportioned). At 2 years postoperatively, this patient has suffered no radiographic complications or undergone any additional spinal procedures. CAP indicates cervicothoracic alignment and proportion.

ACD.[29] Lastly, as cervical deformity is often not in isolation, the RPV, a variable that describes the spatial orientation of the pelvis, was maintained from the original GAP score so as to not lose sight of global alignment when correcting the cervical deformity. In addition, this decision was based on the rationale that spinopelvic alignment impacts the sagittal profile of the cervical spine.[11]

In the present study, patients deemed proportioned by their CAP score had a 0% rate of radiographic complications, whereas the prevalence was 29% for those moderately disproportioned, and 59% for severely disproportioned. Patients with "ideal" proportion by CAP score demonstrated lower radiographic complication rates than those reported in the literature.[10,19,26,30]

Previous studies have examined the relevance of patient-specific correction in the context of mechanical failure, deemed as either revision for DJK or severe radiographic DJK.[19] The authors found tempered corrections relative to a patient's age, even in the presence of severe deformity at baseline, led to lower rates of mechanical failure. Along with emphasizing proportional alignment, these findings corroborate the use of patient-specific alignment targets during surgical planning.

While mitigation of complications is important to emphasize during cervical deformity correction, the ultimate goal of surgical intervention is to restore functionality and improve quality of life. Previous literature has either examined cervical deformity in relation to clinical improvement or the development of complications, and subsequent follow-up studies have found meaningful realignment strategies influential in both.[19,31,32] Therefore, when investigating cervical realignment, we also sought to identify parameters that correlated with clinical improvement when corrected. In doing so, we found patients proportioned and even moderately disproportioned had significantly higher rates of meeting the optimal outcome compared with those severely disproportioned. In summation, patients in a proportioned state demonstrated robust clinical improvement relative to severely disproportioned, while also suffering fewer radiographic complications than both disproportioned states.

At the same time, we recognize that the nature of this work is exploratory, and the performance of the CAP must be verified in other independent cohorts before widespread clinical application can be supported. Additional limitations include the retrospective nature of our database which may contribute to selection, indication, and expertise bias. Given the study design, there may also be the potential for patient clustering. Furthermore, a study of this nature cannot examine causality and both sagittal spinal alignment parameters and mechanical complications may be influenced by other confounding factors such as the underlying spinal diagnoses for which the patient was receiving spinal fusion surgery. The analytic approach should be considered exploratory and, despite controlling for relevant confounders, we could not account for all factors that may influence the outcomes of cervical deformity surgery.

Yet, this score has had successful integration into the preoperative radiographic analysis of this senior surgeon by incorporating the additional measurements into account and creating functions to calculate a score and categorization for each patient. While these have been helpful in preoperative assessment, recommendations regarding specific surgical treatment related to preoperative scoring have not been solidified at our institution. Therefore, we intend to develop further lines of research capable of validating the performance of the CAP score and better accounting for clinical, radiographic, and surgeon-specific confounders. Subsequent work would also assess the ability of the CAP score to prognosticate specific types of failure, associated postsurgical complications, and improvement in HRQL.

CONCLUSIONS

The CAP score represents a tool for analyzing the regional proportionality of the cervical spine in the context of global alignment and prognosticates radiographic complications, reoperations, and clinical outcomes in patients with cervical deformity receiving surgery. Our results emphasize the importance of optimizing the surgical approach in cervical deformity correction to maintain a horizontal gaze while simultaneously matching overall cervical and thoracolumbar alignment to limit complications and maximize clinical improvement. In turn, this may potentiate a more optimal preoperative risk assessment and the development of surgical targets for correction that balance the need for surgical invasiveness against the potential for complications and construct failure. Future work will concentrate on validation and possible modification of this score in the setting of certain populations, including those with severe frailty and osteoporosis.

➢ Key Points

- ❑ The drivers for cervical deformity may be located outside the cervical spine, and it is important to incorporate thoracic and global alignment into correction goals.
- ❑ As opposed to previous classifications and scores, the realignment outcomes of our study may correlate to both clinical improvement and mitigation of complications following cervical deformity surgery.
- ❑ Proportional alignment within the cervical spine, not just lordosis and translation, may better characterize cervical alignment.
- ❑ This exploratory, preliminary approach should guide future research to incorporate patient-specific factors and global alignment into surgical planning for the correction of cervical deformity.

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