Spine

SPINE Volume 46, Number 21, pp 1437–1447

CERVICAL SPINE

Appropriate Risk Stratification and Accounting for Age-Adjusted Reciprocal Changes in the Thoracolumbar Spine Reduces the Incidence and Magnitude of Distal Junctional Kyphosis in Cervical Deformity Surgery

Peter G. Passias, MD,[a] Cole Bortz, BA,[a] Katherine E. Pierce, BS,[a] Nicholas A. Kummer, BS,[a] Renaud Lafage, MS,[b] Bassel G. Diebo, MD,[c] Breton G Line, BS,[d] Virginie Lafage, PhD,[b] Douglas C. Burton, MD,[e] Eric O. Klineberg, MD,[f] Han Jo Kim, MD,[b] Alan H. Daniels, MD,[g] Gregory M. Mundis, MD,[h] Themistocles S. Protopsaltis, MD,[a] Robert K. Eastlack, MD,[i] Daniel M. Sciubba, MD,[j] Shay Bess, MD,[d] Frank J. Schwab, MD,[b] Christopher I. Shaffrey, MD,[k] Justin S. Smith, MD, PhD,[k] and Christopher P. Ames, MD[l], on behalf of the International Spine Study Group (ISSG)

Study Design. Retrospective cohort study of a prospective cervical deformity (CD) database.

Objective. Identify factors associated with distal junctional kyphosis (DJK); assess differences across DJK types.

Summary of Background Data. DJK may develop as compensation for mal-correction of sagittal deformity in the thoracic curve. There is limited understanding of DJK drivers, especially for different DJK types.

Methods. Included: patients with pre- and postoperative clinical/radiographic data. Excluded: patients with previous fusion to L5 or below. DJK was defined per surgeon note or DJK angle (kyphosis from LIV to LIV-2)<-10°, and pre- to postoperative change in DJK angle by<-10°. Age-specific target LL-TK alignment was calculated as published. Offset from target LL-TK was correlated to DJK magnitude and inclination. DJK types: severe (DJK<−20°), progressive (DJK increase>4.4°), symptomatic (reoperation or published disability thresholds of NDI ≥ 24 or mJOA≤14). Random forest identified factors associated with DJK. Means comparison tests assessed differences.

Results. Included: 136 CD patients (61 ± 10 yr, 61%F). DJK rate was 30%. Postop offset from ideal LL-TK correlated with greater DJK angle (r = 0.428) and inclination of the distal end of the fusion construct (r = 0.244, both $P < 0.02$). Seven of the top 15 factors associated with DJK were radiographic, four surgical, and four clinical. Breakdown by type: severe (22%), progressive (24%), symptomatic (61%). Symptomatic had more posterior osteotomies than asymptomatic ($P = 0.018$). Severe had worse NDI and upper-cervical deformity (CL, C2 slope, C0-C2), as well as more posterior osteotomies than nonsevere (all $P < 0.01$). Progressive had greater malalignment both globally and in the cervical spine (all $P < 0.03$) than static. Each type had varying associated factors.

Conclusion. Offset from age-specific alignment is associated with greater DJK and more anterior distal construct inclination, suggesting DJK may develop due to inappropriate realignment. Preoperative clinical and radiographic factors are associated with symptomatic and progressive DJK, suggesting the need for preoperative risk stratification.

From the [a]Department of Orthopedics, NYU Langone Orthopedic Hospital, New York, NY; [b]Department of Orthopedics, Hospital for Special Surgery, New York, NY; [c]Department of Orthopedic Surgery, SUNY Downstate Medical Center, Brooklyn, NY; [d]Department of Orthopaedic Surgery, Rocky Mountain Scoliosis and Spine, Denver, CO; [e]Department of Orthopedic Surgery, University of Kansas Medical Center, Kansas City, KS; [f]Department of Orthopedic Surgery, University of California, Davis, Davis, CA; [g]Department of Orthopaedic Surgery, Warren Alpert School of Medicine, Brown University, Providence, RI; [h]San Diego Center for Spinal Disorders, La Jolla, CA; [i]Division of Orthopaedic Surgery, Scripps Clinic, La Jolla, CA; [j]Department of Neurosurgery, Johns Hopkins University School of Medicine, Baltimore, MD; [k]Department of Neurosurgery, University of Virginia, Charlottesville, VA; and [l]Department of Neurological Surgery, University of California, San Francisco, San Francisco, CA.

Acknowledgment date: December 12, 2020. Acceptance date: January 27, 2021.

The manuscript submitted does not contain information about medical device(s)/drug(s).

The International Spine Study Group (ISSG) is funded through research grants from DePuy Synthes and individual donations.

Relevant financial activities outside the submitted work: board membership, consultancy, grants, royalties, stocks, payment for lecture.

Address correspondence and reprint requests to Peter G. Passias, MD, New York Spine Institute, Division of Spinal Surgery, Departments of Orthopaedic and Neurological Surgery, NYU Langone Medical Center, Orthopaedic Hospital – NYU School of Medicine, 301 East 17th St, New York, NY 10003; E-mail: Peter.Passias@nyumc.org

DOI: 10.1097/BRS.0000000000004033

Key words: age, cervical deformity, complication, distal junctional kyphosis, DJK, reoperation, risk stratification, sagittal alignment, surgery.
Level of Evidence: 3
Spine 2021;46:1437–1447

Cervical deformity (CD) is often associated with a forward shift in cervical alignment—a sagittal imbalance that can displace the head's harmonious center of gravity, fatigue the paraspinal musculature, compress neural elements, disrupt horizontal gaze, and drive further deformity progression. For symptomatic CD patients, restoration of sagittal alignment may require decompression and fusion of the upper-cervical, cervical, and caudal segments. Multiple studies show substantial short-term improvements in both health-related quality of life and sagittal alignment following CD-corrective surgery; however, maintaining satisfactory radiographic outcomes in the long-term remains a challenge.[1–4] For patients undergoing CD-corrective surgery, rates of distal junctional kyphosis (DJK), or postoperative loss of alignment in the distal segments adjacent to the lowest instrumented vertebra, have been reported as high as 24%.[5]

The underlying causes of DJK are not well understood, though many studies in the CD literature suggest that poor bone quality, long fusion constructs across the cervicothoracic junction, and severe preoperative malalignment may contribute to increased risk of DJK development.[6,7] A recent retrospective review of 101 surgical CD patients found excessive preoperative cervical malalignment and thoracic hyperkyphosis to increase the risk of DJK.[8] Severe preoperative malalignment may place patients at risk for residual postoperative deformity, which, in turn, may increase shear stress at the distal end of the fusion construct. It is important to note, however, that not all cases of DJK are clinically symptomatic, require reoperation, or progress to more severe deformity. While prior research has sought to identify risk factors for any DJK occurrence, no previous studies have assessed risk factors for increased DJK magnitude, symptomatic, and progressive DJK subtypes.

This study identifies risk factors for associated with increased DJK magnitude, clinically symptomatic DJK, and DJK that progresses over time. Assessing specific risk factors for these DJK subtypes may help clinicians better understand the complex etiology of DJK, hopefully leading to improvements in both surgical planning and preoperative risk stratification.

MATERIALS AND METHODS

Study Design

This is a retrospective cohort study of a prospective, multicenter CD database. Patients ≥18 years were consecutively enrolled at 13 spine centers across the United States. All enrolling sites obtained Institutional Review Board approval prior to patient enrollment, and all patients provided informed consent prior to enrollment. CD was defined radiographically as baseline cervical kyphosis (C2-C7 sagittal Cobb angle >10°), cervical scoliosis (C2-C7 coronal Cobb angle >10°), C2-C7 sagittal vertical axis (cSVA) >4 cm, or chin-brow vertical angle >25°. All patients included in the present analysis had radiographic and health-related quality of life (HRQL) data available at both baseline and any follow-up interval (3-mo, 6-mo, 1-yr, or 2-yr). Patients with previous fusion to L5 or below were excluded from analysis, as this would preclude the development of DJK.

Data Collection and Radiographic Assessment

Standardized forms collected patient's demographic and comorbidity (including Charlson Comorbidity Index [CCI] score) data. Collection of HRQL data included the Numeric Rating Scales for Neck and Back Pain, Neck Disability Index (NDI), and the 5-dimension, 3-level EuroQol questionnaire (EQ-5D).[9,10] Myelopathy severity was assessed with the modified Japanese Orthopaedic Association (mJOA) questionnaire.[11] Patient frailty was assessed with a previously published CD-specific frailty index, with scores >0.3 indicating frailty.[12]

Standing anterior-posterior and lateral long-cassette radiographs were analyzed as published.[13–15] Long-cassette radiographic analysis included the following parameters: sagittal vertical axis (SVA; horizontal distance from C7 plumbline relative to the posterosuperior corner of S1), pelvic tilt (PT), pelvic incidence (PI), T4-T12 thoracic kyphosis (TK), L1-L4 lumbar lordosis (LL), C2-C7 cervical lordosis (CL), cSVA, and T1 slope.[16] Cervical radiographs allowed for assessment of C0-C2 sagittal Cobb angle (C0-C2), C2 slope, and McGregor's slope (McGS).[17] Mismatches between T1 slope and CL (TS-CL), and PI and LL (PI-LL) were also calculated.

Assessment of Distal Junctional Kyphosis

DJK 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 pre- to postoperative change in DJK angle by<-10°. LIV inclination was defined as the angle between the vertical and the best fit line crossing the center of the LIV, LIV-1, and LIV-2 (Figure 1).

Statistical Analysis

Descriptive analyses summarized patient-related, surgical, and radiographic variables. Patients with DJK were stratified by DJK type: severe (DJK angle <−20°),[18] progressive (DJK angle increase >4.4°, accounting for published sagittal spinal alignment measuring error),[19] and symptomatic (DJK associated with reoperation or published disability thresholds of NDI≥24 or mJOA≤14).[9,11] Random forest analyses, each comprised of 25,000 conditional inference trees, identified the top patient, surgical, and radiographic risk factors associated with overall DJK and each DJK type.[20]

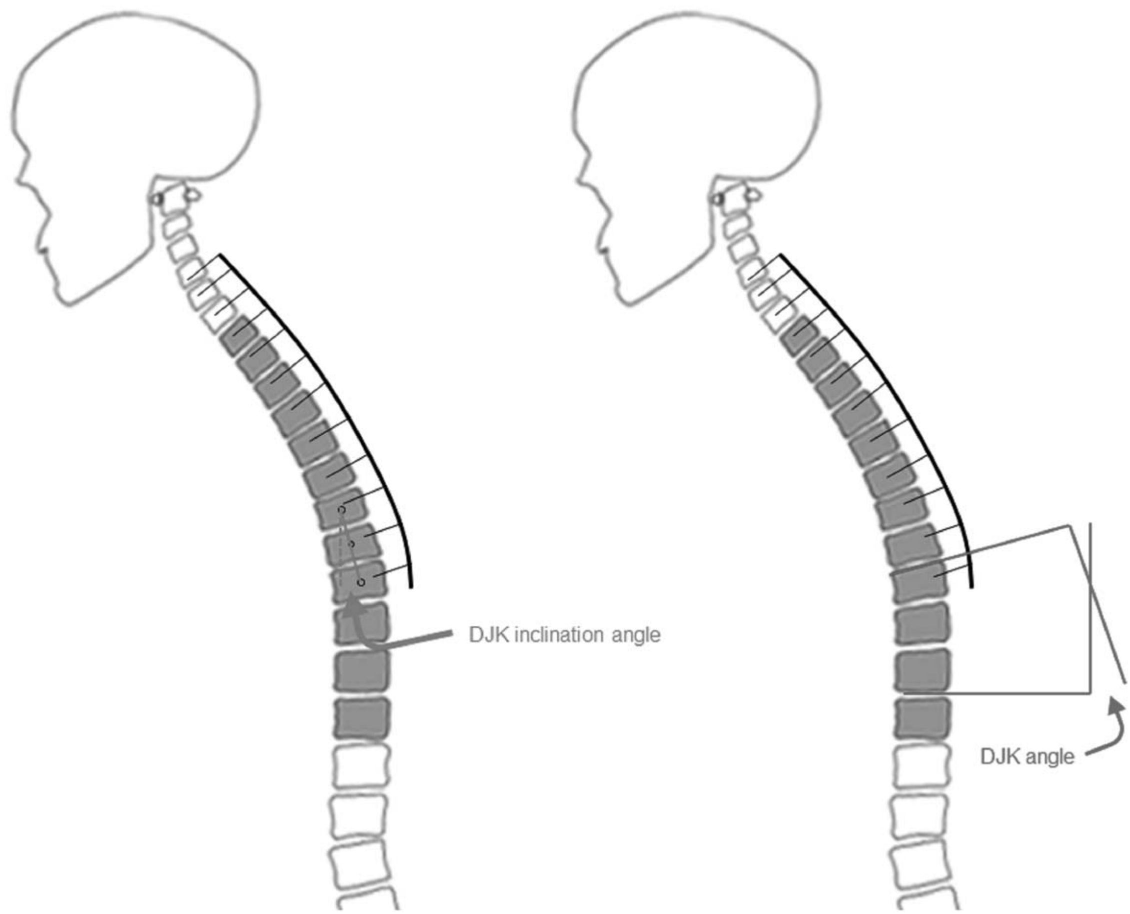

Figure 1. Schematic diagram of DJK inclination angle and DJK angle. DJK indicates distal junctional kyphosis.

Specifically, the top baseline patient-related and surgical risk factors associated with DJK and DJK subtypes were selected according to variable importance tables generated per conditional permutation importance defined by the "varimp" function within the R "party" package.[21] Nonparametric means comparison tests assessed differences in risk factors associated with each DJK type between DJK and no-DJK patients. Paired-samples *t* tests assessed preoperative to postoperative (defined as visit of DJK diagnosis for DJK patients and last available visit for non-DJK patients) changes in alignment within DJK and non-DJK groups. For all patients, age-specific target LL-TK alignment was calculated as published.[22] Postoperative offset from target LL-TK was correlated to both DJK angle magnitude and LIV inclination angle with bivariate Pearson tests. Random forest analyses were conducted with the R statistical software package (R, version 3.2.4, R Foundation for Statistical Computing, Vienna, Austria); all other analyses were conducted with SPSS software (v23.0, Armonk, NY).

RESULTS

Cohort Overview

Of 164 eligible CD patients, 136 (82.8%) met study inclusion criteria and were included in this analysis. The mean age of patients was 60.8 ± 10.4 years (range: 31–83 yr), and 60.9% of patients were female. The mean documented follow-up time from baseline was 14.3 ± 7.8 months (14.7% 3-mo, 9.6% 6-mo, 41.2% 12-mo, 34.6% 24-mo). Table 1 provides a baseline demographic, surgical, and clinical description of the entire cohort, as well as basic demographic differences between DJK and non-JDK groups.

Comorbidity Profiles

The top comorbidities for the cohort included diabetes mellitus (15%), osteoporosis (14%), tumor (11%), and chronic pulmonary disease (8%). Average Charlson Comorbidity Index (CCI) score was $0.9\ 7 \pm 1.33$. Comorbidity analyses were ran between patients who developed DJK and the non-DJK group. Tumors were seen in 20% of DJK patients, while only 8% of non-DJK patients ($P = 0.045$). Lymphomas (DJK: 5%, non-DJK: 0%; $P = 0.033$) and neuromuscular disease (DJK: 12%, non-DJK: 1%; $P = 0.004$) were significantly greater in the DJK group. Osteoporosis diagnosis was larger in the DJK group, but this was not significant (DJK: 20%, non-DJK: 12%; $P = 0.254$). Cerebrovascular disease, chronic pulmonary disease, CHF, connective tissue disease, diabetes, hemiplegia, leukemia, liver disease, PVD, ulcer disease, depression,

TABLE 1. Overall Baseline Demographic, Surgical, Radiographic, and Health-Related Quality of Life Description of the Included Cervical Deformity Cohort (N=136/164)

	Mean (± Standard Deviation) or Rate
Demographics	
Age (yr)	60.8 ± 10.4
Body mass index (kg/m^2)	29.4 ± 8.1
Sex (% female)	60.9%
Surgical factors	
Levels fused	7.8 ± 4.5
Posterior-only surgical approach	47.8%
Anterior-only surgical approach	19.1%
Combined surgical approach	33.1%
Any osteotomy	52.9%
Smith Petersen osteotomy	19.1%
Pedicle subtraction osteotomy	11.7%
Vertebral column resection	5.2%
Upper-most instrumented vertebra (modes)	C2 (44.9%), C3 (29.4%) C4 (12.5%)
Lower-most instrumented vertebra (modes)	T2 (20.6), C7 (16.9%), T3 (10.3%)
Sagittal radiographic alignment	
PI (°)	54.0 ± 11.8
PT (°)	19.5 ± 11.2
PI-LL (°)	1.5 ± 17.6
SVA (mm)	3.0 ± 70.2
TK (°)	−38.6 ± 15.7
CL (°)	−7.0 ± 21.1
TS-CL (°)	36.8 ± 18.2
cSVA (mm)	45.1 ± 25.1
C0-C2 sagittal Cobb (°)	31.6 ± 11.8
McGregor's Slope (°)	3.7 ± 13.5
Health-related Quality of Life Scores	
Neck Disability Index	47.5 ± 17.7
Numeric Rating Scale for Back Pain	5.2 ± 3.1
Numeric Rating Scale for Neck Pain	6.8 ± 2.5
EQ-5D	0.74 ± 0.07
mJOA	13.6 ± 2.7

pancreatic disease, and rheumatoid arthritis were not significant between DJK groups (all $P > 0.05$). CCI score was not significant between the DJK and non-DJK groups (DJK: 1.03, non-DJK: 0.94; $P = 0.745$).

Factors Associated With DJK

Overall, 30.1% of patients developed DJK (44.7% at 3-mo, 21.1% 6-mo, 23.7% 12-mo, 10.5% 24 mo). Breakdown of DJK by type was: severe (22.0%), progressive (24.4%, 5.9°±4.0 degrees), symptomatic (61.0%). In descending order of importance, random forest analysis described the top risk factors for DJK: partial facet joint resection, combined surgical approach, Smith-Petersen osteotomy, C2-C7 cervical lordosis, C2-T3 lordosis, cervical-thoracic pelvic angle, presence of any comorbidity, presence of any tumor, number of posterior osteotomies, C2-C7 SVA, BMI, C2 slope, NDI score, C0-C2 angle, T1-L1 pelvic angle. Table 2 assesses differences in these risk factors between DJK and non-DJK patients, and within DJK subtype groups.

Factors Associated With DJK Types

Table 3 shows random forest results detailing the top 10 risk factors for severe, progressive, and symptomatic DJK. Of the top risk factors associated with severe DJK, 60% were radiographic, 20% were clinical, and 20% were surgical. Of the factors associated with progressive DJK, 80% were radiographic and 20% were surgical. For symptomatic DJK, 60% of risk factors were clinical, 20% radiographic, and 20% surgical.

Radiographic Outcomes

Table 4 shows pre- to postoperative changes in alignment for both DJK and non-DJK groups. Overall, postoperatively, 20.5% of patients matched age-specific LL-TK alignment, 56.1% were overcorrected relative to ideal LL-TK, and 23.5% were under-corrected. There were no differences in DJK rates across patients under-corrected, over-corrected, and matching age-specific LL-TK targets ($P = 0.096$). There was similarly no relationship between

TABLE 2. Comparison of Distal Junctional Kyphosis (DJK) Risk Factors Between DJK and No DJK Patients, Severe and Nonsevere DJK Patients, Progressive and Static DJK Patients, and Symptomatic and Nonsymptomatic DJK Patients

	Overall DJK		Severe DJK		Progressive DJK		Symptomatic DJK	
DJK Risk Factor	DJK (N = 41)	No DJK (N = 95)	Severe (N = 9)	Nonsevere (N = 32)	Progressive (N = 10)	Static (N = 31)	Symptomatic (N = 25)	Asymptomatic (N = 16)
Partial facet joint resections (mean)	***2.8 ± 2.8**	***1.7 ± 2.3**	3.9 ± 3.6	2.4 ± 2.6	1.9 ± 2.2	3.1 ± 3.0	3.2 ± 3.2	2.1 ± 2.1
Combined surgical approach (%)	***48.8%**	***26.3%**	44.4%	50.0%	40.0%	51.6%	52.0%	43.8%
Smith-Petersen osteotomy (%)	***31.7%**	***13.7%**	***66.7%**	***21.9%**	***60.0%**	***22.6%**	40.0%	18.8%
Baseline C2-C7 cervical lordosis (°)	−9.9 ± 24.1	−4.3 ± 18.5	***−27.6 ± 20.0**	***−5.0 ± 23.0**	***−27.2 ± 15.2**	***−4.4 ± 24.0**	−9.2 ± 27.6	−11.0 ± 18.0
Baseline C2-T3 lordosis (°)	−20.7 ± 26.8	−13.9 ± 18.3	***−48.1 ± 22.8**	***−13.3 ± 22.9**	***−43.6 ± 24.5**	***−13.5 ± 23.5**	−18.7 ± 28.0	−23.6 ± 23.5
Baseline cervical-thoracic pelvic angle (°)	5.3 ± 2.5	4.4 ± 2.8	6.6 ± 2.4	5.0 ± 2.5	*7.2 ± 2.2	***4.8 ± 2.4**	5.4 ± 2.9	5.3 ± 1.8
Any comorbidity (%)	***86.5%**	***65.9%**	100.0%	82.8%	100.0%	83.3%	91.3%	78.6%
Any tumor (%)	***19.5%**	***7.6%**	11.1%	21.9%	20.0%	19.4%	20.0%	18.8%
Posterior osteotomies (mean)	3.0 ± 3.7	1.8 ± 2.9	***7.2 ± 4.2**	***1.8 ± 2.6**	4.0 ± 2.9	2.7 ± 3.9	***4.1 ± 4.3**	***1.2 ± 1.6**
Baseline C2-C7 SVA (°)	42.5 ± 19.2	35.2 ± 19.1	52.7 ± 20.9	40.0 ± 18.0	***54.5 ± 19.4**	***38.6 ± 17.8**	41.2 ± 20.8	44.4 ± 16.9
Baseline body mass index (kg/m^2)	30.3 ± 17.7	29.1 ± 7.6	26.5 ± 5.5	31.2 ± 9.6	30.8 ± 7.4	30.1 ± 9.6	29.4 ± 8.7	31.5 ± 9.8
Baseline C2 slope (°)	38.4 ± 24.0	34.9 ± 17.0	***60.2 ± 23.8**	***32.4 ± 20.5**	***59.6 ± 19.8**	***31.7 ± 21.3**	40.1 ± 27.6	35.9 ± 15.1
Baseline Neck Disability Index score	49.5 ± 9.1	46.7 ± 7.6	***59.8 ± 15.0**	***46.5 ± 17.5**	50.4 ± 17.8	49.1 ± 17.6	53.6 ± 16.4	43.0 ± 18.1
Baseline C0-C2 sagittal Cobb angle (°)	34.4 ± 13.5	30.3 ± 10.9	***45.4 ± 9.9**	***31.7 ± 12.9**	***45.6 ± 9.7**	***30.6 ± 12.6**	34.7 ± 13.5	34.1 ± 15.1
Baseline T1-L1 pelvic angle (°)	4.6 ± 7.3	6.4 ± 6.7	1.3 ± 10.2	5.5 ± 6.3	2.9 ± 9.1	5.2 ± 6.8	5.1 ± 9.0	4.0 ± 4.1
Baseline LL-TK (L1S1 − T4T12) (°)	16.0 ± 16.0	12.6 ± 17.5	22.9 ± 20.6	14.1 ± 14.3	17.4 ± 16	15.6 ± 16.3	14.6 ± 18.6	18.3 ± 11

DJK risk factors were identified per random forest analysis.
Bolded and asterisked values denote statistical significance between groups to P<0.050.
SVA indicates sagittal vertical axis.

matching age-specific postop LL-TK alignment and the development of symptomatic DJK (no DJK: 21.3% match *vs* symptomatic DJK: 10.3% match, $P = 0.277$), severe DJK (11.1% match, $P = 0.682$), or progressive DJK (18.2% match, $P = 0.811$).

For patients who developed DJK, offset from age-specific LL-TK correlated with magnitude of DJK angle (Figure 2, $r = 0.415$, $P = 0.010$). Specifically, DJK patients who matched age-specific LL-TK alignment had less severe DJK magnitude (matched: 18.6°, under-corrected: 20.5°, overcorrected: 26.1°). In the overall cohort, greater offset from age-specific LL-TK also correlated with a more anterior distal construct inclination ($r = -0.241$, $P = 0.018$).

Case Examples

Figure 3 shows the pre- and postoperative standing lateral radiographs of a 64-year-old patient with severe DJK (DJK angle: −57.0°). This patient presented with a number of risk factors associated with severe DJK, including severe baseline TS-CL (81.1°), severe C2 slope (80.2°), and bilateral paresthesia.

TABLE 3. Variable Importance Table Generated From Random Forest Analysis Showing the Top 10 Risk Factors for Severe, Progressive, and Symptomatic Distal Junctional Kyphosis (DJK)

Variable Importance	Severe DJK	Progressive DJK	Symptomatic DJK
1	Number of partial facet joint resections	Baseline C1 slope	Number of posterior osteotomies
2	Baseline C2 slope	Baseline C0-C2 sagittal Cobb angle	Baseline frailty
3	Baseline TS-CL	Baseline C2 slope	Baseline hand numbness
4	Baseline bilateral paresthesia	Baseline TS-CL	Baseline Numeric Rating Scale: Neck Pain score
5	Baseline T1 pelvic angle	Baseline C2-C7 cervical lordosis	Number of Smith-Petersen osteotomies
6	Baseline sagittal vertical axis	Number of Smith-Petersen osteotomies	Baseline EQ-5D score
7	Number of posterior osteotomies	Baseline C0 slope	Baseline T4-T12 thoracic kyphosis
8	Baseline C2-C7 cervical lordosis	Apex of deformity driver	Baseline gait disruption
9	Baseline Neck Disability Index score	Lowermost instrumented vertebrae	Baseline PI-LL
10	Baseline C2-S1 SVA	Baseline sagittal vertical axis	Baseline Neck Disability Index score

TABLE 4. Pre- to Postoperative Changes in Radiographic Alignment for Patients That Developed Distal Junctional Kyphosis (DJK) and Patients That Did Not

	DJK Group	Preoperative	Postoperative
PI (°)	Non-DJK	53.6 ± 12.4	53.6 ± 12.5
	DJK	55.0 ± 10.6	55.2 ± 11.4
	P value	0.614	0.420
PT (°)	Non-DJK	19.8 ± 10.9	19.7 ± 10.5
	DJK	19.4 ± 11.0	21.6 ± 10.6
	P value	0.655	0.399
PI-LL (°)	Non-DJK	2.5 ± 15.3	4.9 ± 15.4
	DJK	0.2 ± 20.7	2.7 ± 19.7
	P value	0.322	0.609
SVA (mm)	Non-DJK	8.6 ± 67.3	33.4 ± 62.3
	DJK	−3.5 ± 65.5	21.9 ± 69.5
	P value	0.139	0.094
TK (°)	Non-DJK	−38.2 ± 14.9	−40.6 ± 13.9
	DJK	−39.5 ± 17.8	−46.7 ± 18.6
	P value	0.646	**0.039***
CL (°)	Non-DJK	−4.3 ± 18.5	6.4 ± 16.5
	DJK	−9.9 ± 24.1	7.1 ± 13.4
	P value	0.195	0.146
TS-CL (°)	Non-DJK	35.9 ± 17.6	26.6 ± 11.2
	DJK	39.3 ± 18.7	31.5 ± 15.3
	P value	0.477	**0.008***
cSVA (mm)	Non-DJK	43.2 ± 26.4	36.6 ± 17.9
	DJK	51.4 ± 22.9	47.5 ± 15.7
	P value	0.073	**0.014***
C0-C2 sagittal Cobb (°)	Non-DJK	30.5 ± 10.0	26.9 ± 9.4
	DJK	35.6 ± 12.8	24.2 ± 12.8
	P value	0.087	0.223
McGregor's Slope (°)	Non-DJK	3.5 ± 13.6	−3.6 ± 9.5
	DJK	4.7 ± 14.1	3.6 ± 9.2
	P value	0.872	**0.009***
LL-TK (°)	Non-DJK	12.6 ± 17.5	7.8 ± 17.9
	DJK	16.0 ± 16.0	10.5 ± 15.7
	P value	0.294	0.630

Bolded and asterisked values denote statistical significance between groups to $P < 0.050$.

CL indicates C2-C7 cervical lordosis; cSVA, C2-C7 SVA; PI, pelvic incidence; PT, pelvic tilt; SVA, C7-S1 sagittal vertical axis; TK, T4-T12 thoracic kyphosis; TS-CL, T1 slope minus CL.

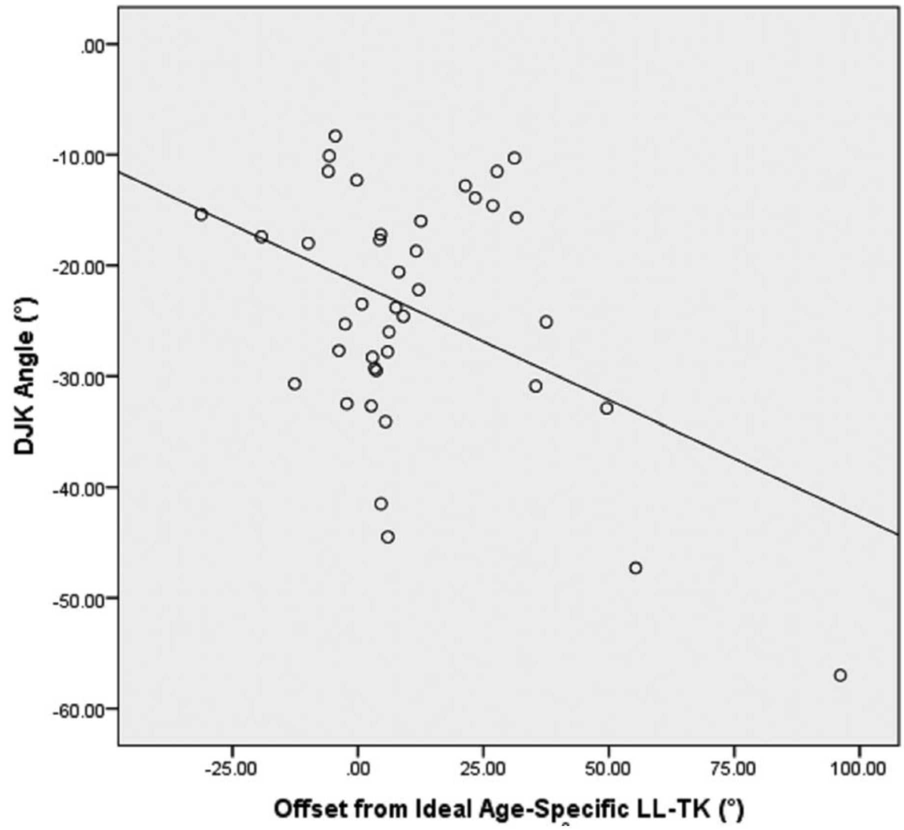

Figure 2. Scatterplot demonstrating the relationship between offset from age-specific LL-TK and magnitude of DJK angle.

Figure 3. Case example of severe DJK.

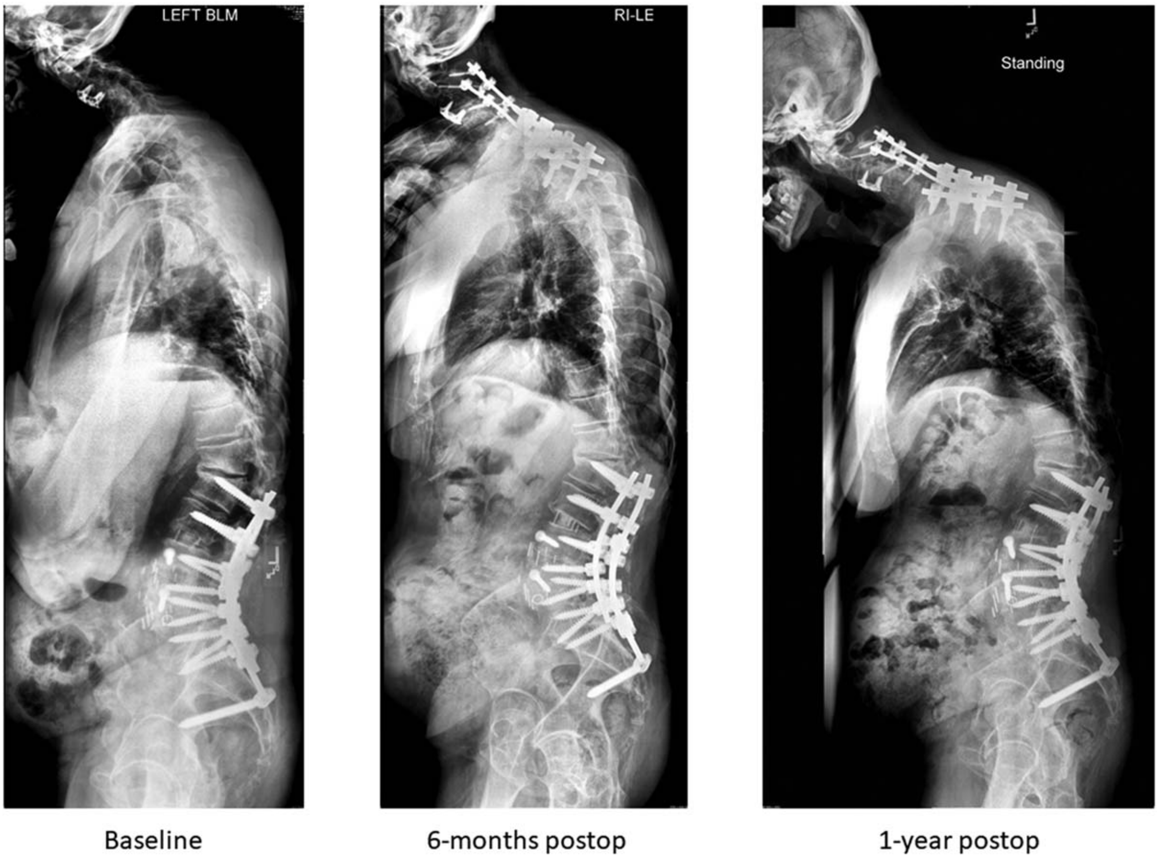

Figure 4. Case example of progressive DJK.

Figure 4 shows a 73-year-old patient with DJK that became progressively worse from 6-months (DJK angle: −24.6°) to 1-year (DJK angle: −35.3°) postop. This patient presented with multiple risk factors for progressive DJK, including cervical kyphosis (C2-C7 CL: −25.5°), severe TS-CL (53.0°), and global sagittal deformity (SVA: 52.8 mm).

Figure 5 shows a 60-year-old patient that developed symptomatic DJK at 3 months (NDI: 50, mJOA: 13). This patient had the following symptomatic DJK risk factors: frailty (mCD-FI score: 0.42), severe baseline back pain (NRS Back: 8/10), and baseline hyper-kyphosis (−69.8°).

Figure 6 presents a case example highlighting the relationship between DJK magnitude and offset from age-specific ideal LL-TK alignment. The left panel shows a patient corrected within 8.2° of ideal postoperative LL-TK, with a DJK angle of −20.6°. The right panel shows a patient with a greater offset from ideal LL-TK (37.5°), and a correspondingly greater DJK angle (−25.4°).

DISCUSSION

Junctional kyphosis is well studied in the context of surgery for adult spinal deformity, with a number of studies exploring the causes and risk factors for postoperative kyphotic deformity at the uppermost instrumented vertebra.[23] In contrast, the underlying mechanisms and risk factors for DJK are not well outlined in the literature. While some cases of DJK may result in a dramatic loss of correction that requires surgical revision, other cases can be clinically asymptomatic, having little overall impact on patient-reported outcomes.[24] Previous studies have identified preoperative clinical and radiographic factors associated with DJK; however, to date, no publications have investigated specific risk factors for severe, symptomatic, and progressive DJK types.[8] This study sought to further investigate factors associated with the development of DJK following CD-corrective surgery, highlighting risk factors for clinically relevant DJK subtypes.

Compared to previous publications in the CD literature which cite 1-year postoperative DJK rates around 24%, our study showed a slightly higher overall DJK rate of 30%—an increase that may be explained by our inclusion of patients who developed DJK at 2-years postoperative.[2,8] Of all the DJK cases identified in our analysis, 61% were clinically symptomatic, 24% were progressive, and 22% were radiographically severe, defined as a postoperative DJK angle of more than 20°. The DJK risk factors identified in the present analysis, including combined surgical approach, use of Smith-Petersen osteotomy, and severe sagittal malalignment, are all consistent with DJK risk factors previously published in the CD literature, and are comparable to risk factors associated with PJK in patients undergoing surgery for adult spinal deformity.[8,25] These results further reinforce the prevailing

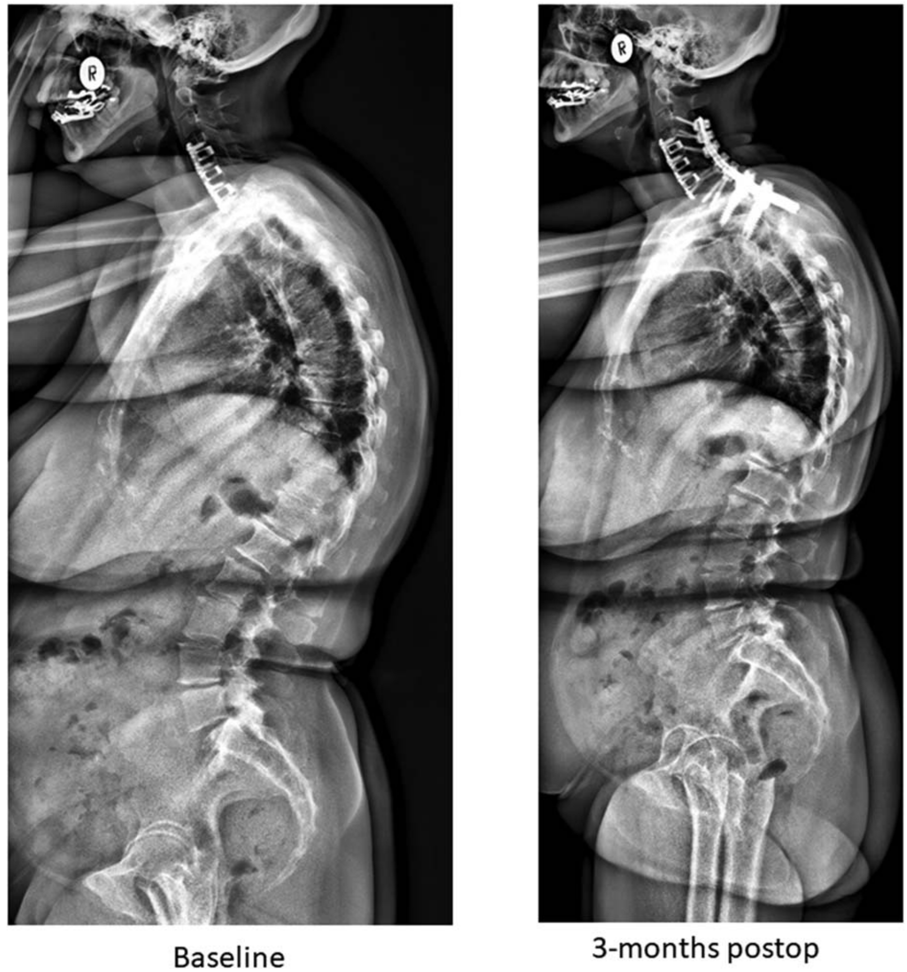

Figure 5. Case example of symptomatic DJK.

assumption in the literature that the etiology of DJK is complex, with multiple different contributing factors.

Across DJK categories, our study showed marked variation in the types of factors predicting DJK occurrence. For example, while 60% and 80% of the top risk factors associated with severe and progressive DJK, respectively, were radiographic, the majority of risk factors associated with symptomatic DJK were clinical. Random forest analysis highlighted the preoperative clinical factors of frailty, hand numbness, and neck pain/disability as all associated with symptomatic DJK. Although DJK certainly has underlying biomechanical drivers, our study suggests that the development of symptomatic DJK may be associated with higher levels of baseline disability and vulnerability to environmental stressors. These results are among the first in the CD literature to offer an explanation as to why some cases of DJK are clinically relevant, and others are not.

Interestingly, our study showed a significant correlation between magnitude of DJK angle and offset from age-specific ideal thoracolumbar alignment. The relationship between age and sagittal spinal alignment is well explored in the literature, and recent research proposes age-specific operative realignment goals for adult deformity patients.[22,26–28] An important study by Lafage *et al* demonstrated that for surgical adult spinal deformity patients, overcorrection relative to ideal age-specific sagittal alignment is associated with increased risk of proximal junctional kyphosis (PJK), perhaps due to compensatory reciprocal changes in the thoracic and lumbopelvic curves.[29] In the same study, Lafage *et al* also showed significant positive correlations between PJK angle magnitude and offset from age-specific ideal PT, PI-LL, and SVA alignment. As our study similarly revealed a proportional relationship between surgical overcorrection and magnitude of DJK angle, our results seem to suggest that DJK may develop as a result of inappropriate realignment.

The small sample size of DJK patients in this study, particularly when stratified by DJK type subgroup, is a key limitation of our study, limiting the statistical power of our findings. Although the overall DJK risk factors identified in our analysis are similar to those previously published, the risk factors identified for each DJK type subgroup likely reflect a spectrum of actual risks, some of which are truly associated with the DJK type, and others which are just the result of statistical noise. Additionally, it is important to note that the age-specific LL-TK alignment targets used in our analysis were developed in a population of adult spinal deformity patients; they are not specific to

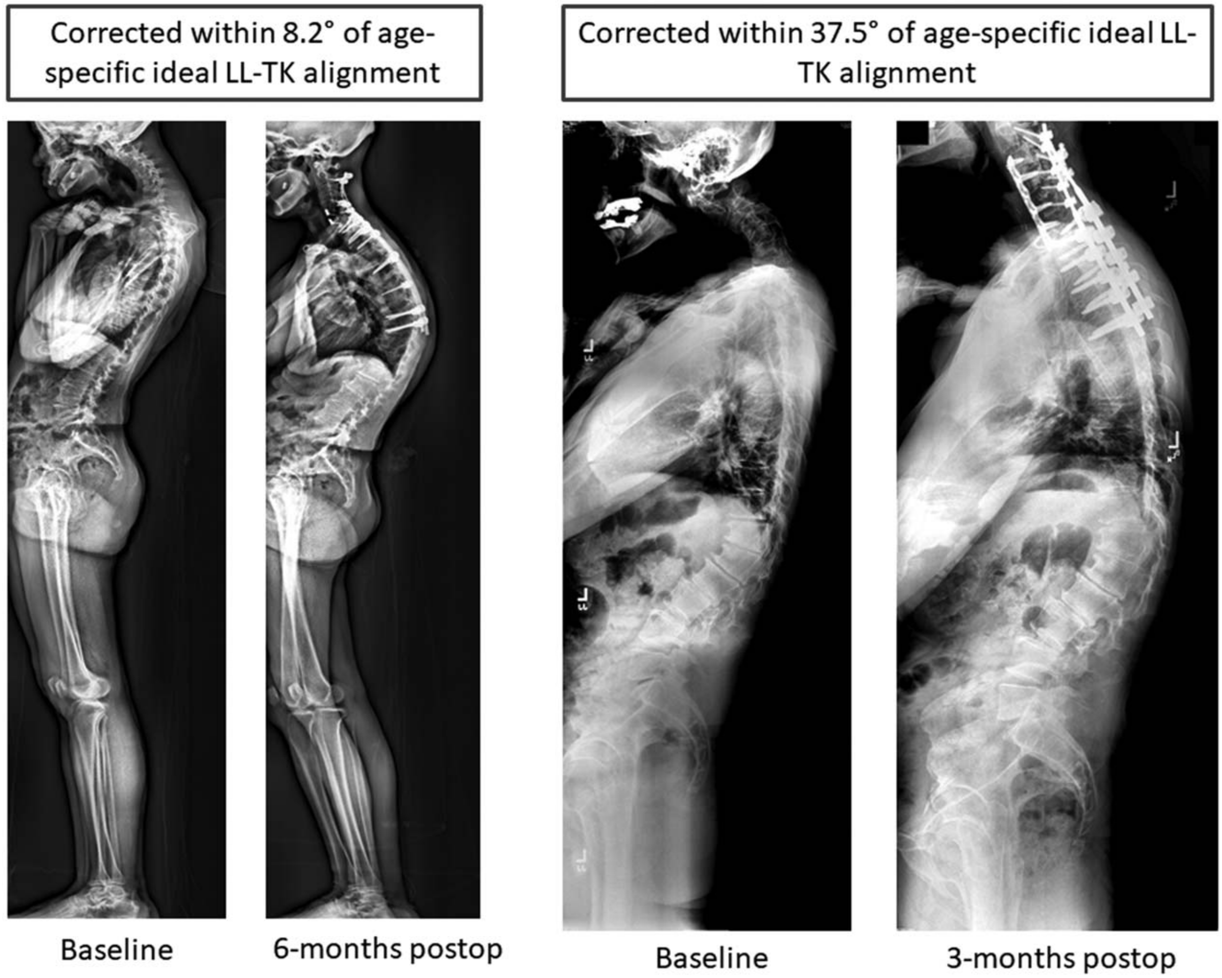

Figure 6. Case examples demonstrating the relationship between offset from age-specific LL-TK and magnitude of DJK angle.

CD patient populations. We opted to use these non-CD-specific alignment goals in our analysis because no such alignment targets have been proposed for CD patients—this is certainly an area of research that warrants further attention. Lastly, the CD cohort included in our analysis presented with severe preoperative deformity and was older, with a mean age of 61 years. The generalizability of our results in a less deformed, less comorbid population is uncertain.

CONCLUSION

For patients undergoing CD-corrective surgery, postoperative offset from age-specific LL-TK alignment is associated with greater DJK magnitude, suggesting that DJK may develop as a result of inappropriate realignment. Across patients grouped by severe, progressive, and symptomatic DJK, there was appreciable variation in the factors associated with DJK occurrence. The results of this study further illuminate the complex etiology of DJK, and suggest that effective preoperative risk stratification may help mitigate the incidence of clinically relevant DJK.

➢ Key Points

- ❑ Distal Junctional Kyphosis, which can be broken down into severe, progressive, and symptomatic, is a prevalent complication among adult Cervical Deformity patients.
- ❑ Top risk factors include radiographic, clinical, and surgical components that vary in association by Distal Junctional Kyphosis type.
- ❑ Patients with appropriate alignment postsurgery had reduced instance of Distal Junctional Kyphosis, indicating that this complication may result due to alignment offset.

References

1. Ailon T, Smith JS, Shaffrey CI, et al. Outcomes of operative treatment for adult cervical deformity: a prospective multicenter assessment with 1-year follow-up. *Neurosurgery* 2018;83:1031–9.

2. Protopsaltis TS, Ramchandran S, Hamilton DK, et al. Analysis of successful versus failed radiographic outcomes after cervical deformity surgery. *Spine (Phila Pa 1976)* 2018;43:E773–81.
3. Passias PG, Bortz C, Horn S, et al. Drivers of cervical deformity have a strong influence on achieving optimal radiographic and clinical outcomes at 1 year after cervical deformity surgery. *World Neurosurg* 2018;112:e61–8.
4. Passias PG, Horn SR, Oh C, et al. Evaluating cervical deformity corrective surgery outcomes at 1-year using current patient-derived and functional measures: are they adequate?. *J Spine Surg* 2018;4:295–303.
5. Protopsaltis TS, Ramchandran S, Kim HJ, et al. Analysis of Early Distal Junctional Kyphosis (DJK) after cervical deformity correction. *Spine J* 2016;16:S355–6.
6. Koller H, Ames C, Mehdian H, et al. Characteristics of deformity surgery in patients with severe and rigid cervical kyphosis (CK): results of the CSRS-Europe multi-centre study project. *Eur Spine J* 2019;28:324–44.
7. Ramchandran S, Protopsaltis TS, Ames CP. Cervicothoracic Kyphosis (Dropped Head Deformity) Surgery Complication. In: Mummaneni PV, Park P, Crawford III C, Kanter AS, Glassman SD, editors. *Spinal Deformity: A Case-Based Approach to Managing and Avoiding Complications [Internet]*. Cham: Springer International Publishing; 2018. pp. 67–74.
8. Passias PG, Vasquez-Montes D, Poorman GW, et al. Predictive model for distal junctional kyphosis after cervical deformity surgery. *Spine J* 2018;17 (10 supplement):S244.
9. Vernon H, Mior S. The Neck Disability Index: a study of reliability and validity. *J Manip Physiol Ther* 1991;14:409–15.
10. Smith JS, Line B, Bess S, et al. The Health Impact of Adult Cervical Deformity in Patients Presenting for Surgical Treatment: Comparison to United States Population Norms and Chronic Disease States Based on the EuroQuol-5 Dimensions Questionnaire. *Neurosurgery* 2017;80:716–25.
11. Tetreault L, Kopjar B, Nouri A, et al. The modified Japanese Orthopaedic Association scale: establishing criteria for mild, moderate and severe impairment in patients with degenerative cervical myelopathy. *Eur Spine J* 2017;26:78–84.
12. Passias PG, Bortz CA, Segreto FA, et al. Development of a modified cervical deformity frailty index: a streamlined clinical tool for preoperative risk stratification. *Spine (Phila Pa 1976)* 2019;44:169–76.
13. Champain S, Benchikh K, Nogier A, et al. Validation of new clinical quantitative analysis software applicable in spine orthopaedic studies. *Eur Spine J* 2006;15:982–91.
14. Rillardon L, Levassor N, Guigui P, et al. [Validation of a tool to measure pelvic and spinal parameters of sagittal balance]. *Rev Chir Orthop Reparatrice Appar Mot* 2003;89:218–27.
15. O'Brien MF, Kuklo TR, Blanke KM, Lenke LG. Spinal Deformity Study Group Radiographic Measurement Manual. 2005; Available at: http://www.oref.org/docs/default-source/default-document-library/sdsg-radiographic-measuremnt-manual.pdf?sfvrsn=2. Accessed 12 July, 2020.
16. Diebo BG, Varghese JJ, Lafage R, et al. Sagittal alignment of the spine: what do you need to know?. *Clin Neurol Neurosurg* 2015;139:295–301.
17. Lafage R, Challier V, Liabaud B, et al. Natural head posture in the setting of sagittal spinal deformity: validation of chin-brow vertical angle, slope of line of sight, and McGregor's Slope With Health-Related Quality of Life. *Neurosurgery* 2016;79:108–15.
18. Protopsaltis TS, Stekas N, Lafage R, et al. Saturday, September 29, 2018 9:00 am–10:00 am Impact of Adult Deformity Correction: 261. Can we define clinically relevant DJK in cervical deformity surgery? Spine J. 2018;18:S129–30.
19. Vila-Casademunt A, Pellisé F, Acaroglu E, et al. The reliability of sagittal pelvic parameters: the effect of lumbosacral instrumentation and measurement experience. *Spine (Phila Pa 1976)* 2015;40:E253–8.
20. Breiman L. Random forests. *Mach Learn* 2001;45:5–32.
21. Strobl C, Boulesteix A-L, Kneib T, et al. Conditional variable importance for random forests. *BMC Bioinformatics* 2008;9:307.
22. Lafage R, Schwab F, Challier V, et al. Defining spino-pelvic alignment thresholds: should operative goals in adult spinal deformity surgery account for age?. *Spine (Phila Pa 1976)* 2016;41:62–8.
23. Lee J, Park Y-SS. Proximal junctional kyphosis: diagnosis, pathogenesis, and treatment. *Asian Spine J* 2016;10:593–600.
24. Lundine K, Turner P, Johnson M. Thoracic hyperkyphosis: assessment of the distal fusion level. *Glob Spine J* 2012;2:65–70.
25. Park S-HS-J, Lee C-S, Chung S-S, et al. Different risk factors of proximal junctional kyphosis and proximal junctional failure following long instrumented fusion to the sacrum for adult spinal deformity: survivorship analysis of 160 patients. *Neurosurgery* 2017;80:279–86.
26. Lafage V, Schwab FJ, Skalli W, et al. Standing balance and sagittal plane spinal deformity: analysis of spinopelvic and gravity line parameters. *Spine (Phila Pa 1976)* 2008;33:1572–8.
27. Hasegawa K, Okamoto M, Hatsushikano S, et al. Normative values of spino-pelvic sagittal alignment, balance, age, and health-related quality of life in a cohort of healthy adult subjects. *Eur Spine J* 2016;25:3675–86.
28. Passias PG, Horn SR, Frangella NJ, et al. Full-body analysis of adult spinal deformity patients' age-adjusted alignment at 1 year. *World Neurosurg* 2018;114:e775–84.
29. Lafage R, Schwab F, Glassman S, et al. Age-adjusted alignment goals have the potential to reduce PJK. *Spine (Phila Pa 1976)* 2017;42:1275–82.