Predicting the Occurrence of Postoperative Distal Junctional Kyphosis in Cervical Deformity Patients

BACKGROUND: Distal junctional kyphosis (DJK) development after cervical deformity (CD)-corrective surgery is a growing concern for surgeons and patients. Few studies have investigated risk factors that predict the occurrence of DJK.

OBJECTIVE: To predict DJK development after CD surgery using predictive modeling.

METHODS: CD criteria was at least one of the following: C2-C7 Coronal/Cobb > 10°, C2-7 sagittal vertical axis (cSVA) > 4 cm, chin-brow vertical angle > 25°. DJK was defined as the development of an angle < -10° from the end of fusion construct to the second distal vertebra, and change in this angle by < -10° from baseline to postoperative. Baseline demographic, clinical, and surgical information were used to predict the occurrence of DJK using generalized linear modeling both as one overall model and as submodels using baseline demographic and clinical predictors or surgical predictors.

RESULTS: One hundred seventeen CD patients were included. At any postoperative visit up to 1 yr, 23.1% of CD patients developed DJK. DJK was predicted with high accuracy using a combination of baseline demographic, clinical, and surgical factors by the following factors: preoperative neurological deficit, use of transition rod, C2-C7 lordosis (CL) < -12°, T1 slope minus CL > 31°, and cSVA > 54 mm. In the model using only baseline demographic клинических/клинических predictors of DJK, presence of comorbidities, presence of baseline neurological deficit, and high preoperative C2-T3 angle were included in the final model (area under the curve = 87%). The final model using only surgical predictors for DJK included combined approach, posterior upper instrumented vertebrae below C4, use of transition rod, lack of anterior corpectomy, more than 3 posterior osteotomies, and performance of a 3-column osteotomy.

CONCLUSION: Preoperative assessment and consideration should be given to these factors that are predictive of DJK to mitigate poor outcomes.

KEY WORDS: Preoperative factors, DJK, Distal junctional kyphosis, Predictive analysis

Cervical deformity (CD) includes a wide range of disorders and etiologies, including spondylosis, trauma, congenital, ankylosing spondylitis, among others.1,2 Severe CD can result in debilitating disability related to decreased neurological function. While thoracolumbar deformities are more highly studied in the literature, fewer studies exist examining assessments and treatment techniques for CD.3-5 Recent advancements have led to the development of a classification system for CD and to improvements in surgical techniques and procedures performed; however, complications following CD-corrective surgery are daunting.5,6

The development of distal junctional kyphosis (DJK) after CD surgery is a growing concern for surgeons and patients. DJK is defined as a loss of radiographic alignment 1 or 2 levels distal to the lowest instrumented vertebra and has been reported as resulting from adjacent level failure,
spondylolisthesis, fixation failure, and other causes. The durability of CD correction remains a challenge, and there is a lack of knowledge regarding specific predictors and causes of DJK occurrence.

Predictive analytics have been widely used in other fields of medicine to assess patient-specific factors that predict an outcome of interest. However, for spine surgery outcomes, this statistical method has not been utilized as frequently. Given that surgeons and their patients are investing in obtaining the best possible outcome for each patient after surgery, identifying factors as risk factors for development of a complication are highly important.

One recent study created a statistical model that predicted poor postoperative surgical outcomes after thoracolumbar deformity surgery, including radiographic and surgical predictors of a poor outcome. In the cervical spine literature, however, no studies of this sort exist examining patient-specific predictive factors for a poor radiographic outcome following CD-corrective surgery.

Few studies have investigated baseline and procedural risk factors that predict the occurrence of DJK in a CD population. Therefore, the aim of this study was to predict DJK development after CD-corrective surgery using predictive modeling incorporating demographic, clinical, and surgical predictive factors.

METHODS

Data Source

A prospectively-collected database consisting of enrolled CD patients from 13 sites within the United States was retrospectively reviewed. Prior to commencement of the study, informed consent was given by each patient included in the study and approval from the Internal Review Board was obtained at each participating site. Parameters for inclusion were set based on the ages of patients being ≥18 yr and radiographic evidence of CD at baseline assessment, which is defined as the presence of at least one of the following: C2-7 sagittal vertical axis (cSVA) > 4 cm, chin-brow vertical angle (CBVA) > 25°, cervical scoliosis (C2-7 coronal Cobb angle > 10°), or cervical kyphosis (C2-7 Cobb angle > 10°). Furthermore, CD patients who had available baseline and 1-yr follow-up data following the radiographic inclusion criteria were included in the study while patients with active tumors or infections were excluded.

Data Collection

Patient clinical data and demographics such as age, sex, Charlson Comorbidity Index (CCI), body mass index (BMI), and prior cervical surgery were collected. Additionally, data on surgical trends such as operative time, surgical approach, number of levels fused, use and number of osteotomies, off-label use of bone-morphogenetic protein 2, instrumentation used, and estimated blood loss were collected.

Patients were evaluated at baseline and a 1-yr postoperative follow-up visit using full-length free standing lateral spine radiographs (36° long-cassette). Radiographic analysis was completed at a single center with standard techniques using SpineView® (ENSAM, Laboratory of Biomechanics, Paris, France). Spino pelvic parameter measurements consisted of pelvic incidence minus lumbar lordosis (PI-LL), sagittal vertical axis (SVA), and pelvic tilt (PT). Cervical spine parameters measured encompassed C2-C7 lordosis (CL), CBVA, cSVA, and T1 slope minus CL (TS-CL).

Patient Grouping

The development of DJK was defined as the progression of an angle < −10° from the end of fusion construct to the second distal vertebra in addition to a change in the same angle by < −10° from baseline to postoperative time point (either 3-mo, 6-mo, or 1-yr follow-up).

Statistical Analyses

The baseline demographics, clinical, and surgical characteristics of subjects were first summarized using descriptive statistics in mean ± standard deviation for continuous variables or counts (%) for categorical variables. Each variable’s “predictability” was then assessed using logistic regression in univariable and multivariable manners as follows. A univariable analysis was done for an initial data analysis in order to present variables that were statistically significant and clinically meaningful. Variables that displayed a P of < .10 in the initial analysis and were clinically significant were then entered into the multivariable model. Using the Akaike’s Information Criterion (AIC), a stepwise forward regression was completed to select variables that should be included in each of the success measure models. A statistical improvement in the model was achieved for every additional variable in the stepwise process by significantly lowering the analogous AIC. Finally, an assessment of the internal validity was completed with a bootstrapping procedure. The entire modeling process was repeated to include variable selection in 200 samples drawn with replacement from the original sample. The performance of the selected prediction model and the simple rule that was developed from each bootstrap sample in the original sample were determined. Included performance measures were sensitivity, the average area under the receiver operating characteristic curve, and specificity for outcome measures.

Since some patients were missing preoperative and surgical variables not all regressions consisted of the same number of patients. Patients were excluded from the model if there was missing data for an outcome. The initial stepwise regression only consisted of patients that had all variables present, but after selecting for significant variables the regression model was repeated to include as much data that was available.

To ensure that the number of individuals was adequate for the number of predictors, a minimum of 10 events for each covariate were included in all of the models. With a total of 117 individuals, the multivariable model could include up to 11 independent variables. Due to the limited available samples, one overall model and submodels were considered using (1) baseline demographic and clinical predictors and (2) surgical
RESULTS

Patient Demographics

One hundred seventeen CD patients were included (60.7 ± 10.6 yr, 61.4% female, BMI: 29.8 ± 8.5 kg/m², Table 1). The most common diagnoses for these CD patients were degenerative kyphosis (50.9%), cervical stenosis (12%), and iatrogenic kyphosis (10.9%). 30.7% had depression, 38.2% had a history of smoking, and 13.2% had osteoporosis. 39.3% of patients had a prior cervical spine surgery. At any postoperative visit up to 1 yr, 27 (23.1%) CD patients developed DJK.

Patients who developed postoperative DJK did not differ in demographics or surgical details compared with patients who did not develop DJK (Table 1). Twenty two (81.5%) of patients developed DJK by 3-mo follow-up, with 4 (14.8%) developing DJK by 1-yr and 1 (3.7%) at 6-mo follow-up. The location of the lowest instrumented vertebra for patients who developed DJK is shown in Figure 1. Of 27, 16 DJK patients developed severe DJK with an angle ≤ 20°. 4 patients underwent a reoperation for the developed DJK.

Surgical Details

CD correction for these patients involved a mean 7.2 ± 3.6 levels fused, with 45.3% posterior, 19.7% anterior, 35% combined approach surgeries. 16.2% of cases had a 3-column osteotomy performed.

Pre- and Postoperative Radiographic Alignment

DJK patients had significantly more severe cervical malalignment at baseline, with higher TS-CL (44.5° vs 34.8°), C2-CL (16.6° vs 5.7°), cSVA (55.6 mm vs 41.5 mm), C2-T3 angle (28.6° vs 13.5°), and C2 slope (46.2° vs 34.2°, all P < .05). All parameters significantly more malaligned in the DJK patients at baseline were significantly worse at 1 yr in the DJK population after correction except for CL (Table 2).

Baseline Demographic and Clinical Predictors of DJK Occurrence

In the model using only baseline demographic and clinical predictors of DJK, presence of comorbidities (most commonly diabetes, hypertension, and depression), presence of baseline neurological deficit, and high preoperative C2-T3 angle were included in the final model (AUC = 87%, Table 4B).

Surgical Predictors of DJK Occurrence

DJK occurrence could be predicted with high accuracy (AUC = 81%) using only surgical predictors using the following combination of factors (Table 4C): combined approach (OR: 7.9, CI: 1.7-37.1), posterior Upper Instrumented Vertebrae (UIV) below C4 (OR: 0.59, CI: 0.33-1.1), use of transition rod (OR:...
PREDICTING DJK IN CERVICAL DEFORMITY PATIENTS

FIGURE 1. The distribution of the location of the lowest instrumented vertebra for patients who developed DJK.

TABLE 2. Radiographic Alignment Parameters at Baseline and 1-Year Compared Between DJK and Non-DJK Patients

<table>
<thead>
<tr>
<th>Parameter</th>
<th>DJK</th>
<th>Non-DJK</th>
<th>P value</th>
<th>DJK</th>
<th>Non-DJK</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pelvic tilt (°)</td>
<td>19.67 ± 12.07</td>
<td>19.25 ± 11.5</td>
<td>.868</td>
<td>20.0 ± 12.2</td>
<td>18.31 ± 10.9</td>
<td>.560</td>
</tr>
<tr>
<td>PI-LL (°)</td>
<td>–0.8 ± 21.46</td>
<td>2.35 ± 18.1</td>
<td>.451</td>
<td>0.03 ± 22</td>
<td>3.34 ± 16.6</td>
<td>.484</td>
</tr>
<tr>
<td>T4-T12 thoracic kyphosis (°)</td>
<td>–40.37 ± 17.71</td>
<td>–37.59 ± 15.16</td>
<td>.426</td>
<td>–46 ± 17.2</td>
<td>–40.9 ± 15</td>
<td>.231</td>
</tr>
<tr>
<td>T1 slope (°)</td>
<td>28.09 ± 12.17</td>
<td>29.14 ± 17.31</td>
<td>.730</td>
<td>36.3 ± 14.4</td>
<td>33.5 ± 14.9</td>
<td>.482</td>
</tr>
<tr>
<td>TS-CL (°)</td>
<td>44.52 ± 16.6</td>
<td>34.79 ± 18.97</td>
<td>.024*</td>
<td>34.1 ± 14.4</td>
<td>25.3 ± 11.9</td>
<td>.011</td>
</tr>
<tr>
<td>C2-C7 lordosis (°)</td>
<td>–16.62 ± 17.47</td>
<td>–5.69 ± 21.6</td>
<td>.024*</td>
<td>2.2 ± 14.6</td>
<td>8.3 ± 15.9</td>
<td>.152</td>
</tr>
<tr>
<td>cSVA (mm)</td>
<td>55.65 ± 20.77</td>
<td>41.47 ± 26.2</td>
<td>.016*</td>
<td>48.2 ± 16.1</td>
<td>38.2 ± 18.2</td>
<td>.039</td>
</tr>
<tr>
<td>C2-T3 angle (°)</td>
<td>–28.64 ± 23.36</td>
<td>–13.47 ± 20.17</td>
<td>4.02*</td>
<td>–8.74 ± 13</td>
<td>1.1 ± 18.1</td>
<td>.035</td>
</tr>
<tr>
<td>C2-T3 SVA (mm)</td>
<td>85.8 ± 32.23</td>
<td>72.13 ± 41.64</td>
<td>.137</td>
<td>85.8 ± 23.3</td>
<td>72.7 ± 29.2</td>
<td>.086</td>
</tr>
<tr>
<td>C2 slope (°)</td>
<td>46.23 ± 19.71</td>
<td>34.21 ± 19.65</td>
<td>.009*</td>
<td>33.8 ± 14.9</td>
<td>24 ± 12.7</td>
<td>.008</td>
</tr>
<tr>
<td>SVA (mm)</td>
<td>–11.6 ± 68.02</td>
<td>5.36 ± 70.33</td>
<td>.281</td>
<td>16.1 ± 69</td>
<td>23.5 ± 69.1</td>
<td>.691</td>
</tr>
</tbody>
</table>

Significance was set at P < .05 and noted by an asterisk (*).

2.8, CI: 0.8-10.2), lack of anterior corpectomy (OR: 0.5, CI: 0.2-1.1), more than 3 posterior osteotomies (OR: 1.4, CI: 1.1-1.8), and performance of a 3-column osteotomy (OR: 2.9, CI: 0.8-11.3).

Case Examples

Two patients who developed DJK postoperatively are displayed in Figures 2 and 3. Figure 2 shows a 59-yr-old female CD patient who underwent a 15 level fusion. At baseline, the C2-T3 angle was –68.5°, TS-CL was 71.3°, CL was –20.8°, and cSVA was 91.7 mm. This patient developed DJK by 3 m postoperative, predicted by her depression, osteoporosis, and Hoffman's sign at baseline. The patient also had surgical predictors of DJK including the use of a posterior transition rod and 5 osteotomies. Figure 3 displays a 76-yr-old female CD patient who underwent a 10 level fusion. At baseline, the TS-CL was 44.4°, CL was –13.1°, cSVA was 50.9 mm. DJK developed by 3 mo, with primarily surgical predictors, including combined approach, use of a transition rod, 4 posterior osteotomies, and no baseline neurological deficit.

DISCUSSION

DJK development after CD surgery is a growing concern for surgeons and patients. With the lack of knowledge regarding specific predictors and causes of DJK occurrence, it is
imperative to better understand what these factors are and how they contribute to DJK to improve patient outcomes.8–10 Limited literature exists regarding specific baseline and procedural factors that can predict DJK development after CD-corrective surgery.

Therefore, we sought to develop predictive models for DJK development in a CD cohort. We found that DJK occurred in 23.1% of our surgical CD cohort.

DJK occurrence was predicted with high accuracy (AUC = 87%) using a combination of demographic, clinical, and surgical factors. The model was applied to different deformity severity at baseline, by way of the Ames CD classification system, and demonstrated predictability across most severity groups. Development of DJK occurred most commonly within 3 mo postoperatively, which is similar to previously reported rates of proximal junctional kyphosis timing.17,18 Additionally, DJK patients had significantly more severe cervical malalignment at baseline, as measured by TS-CL, CL, cSVA, C2-T3 angle, and C2 slope. Our model that included a combination of demographic, clinical, and surgical predictors of DJK included higher baseline sagittal malalignment, with CL < −12°, TS-CL > 31°, and cSVA > 54 mm. These radiographic factors are specific to a CD cohort, given that these parameters have been well documented in the literature as indicative of sagittal malalignment.5,19 In CD surgery, the hypermobile cervical spine is fused and the lower portion of the spine is unfused; however, the stressors are still the same as for proximal junctional kyphosis.

These findings in a CD cohort are the ancillary to the results in the lumbar spine looking at proximal junctional kyphosis. One meta-analysis reported that preoperative sagittal malalignment is a risk factor for proximal junctional kyphosis, with higher preoperative SVA, thoracic kyphosis, pelvic incidence, and lower
sacral slope and pelvic retroversion have all been shown to occur prior to proximal junctional kyphosis. Other predictors in the overall predictive model included preoperative neurological deficit and the use of a transition rod. These factors have also previously been reported in the thoracolumbar proximal junctional kyphosis literature as risk factors.

Though still understudied in the literature, several recent reports have investigated DJK development and risk factors in prospective CD cohorts. Recent reports have shown that more levels fused, higher grade osteotomies, and use of posterior transition rods all occurred at higher rates for CD patients who developed DJK than those who did not have DJK. Another study used random forest analysis to rank significant risk factors for DJK development in a CD population, finding that baseline radiographic malalignment with CD-specific parameters including TS-CL and CL, as well as combined approach and higher grade osteotomies were significant risk factors for DJK. These findings are in line with the results of our predictive models shown here; however, our analysis has combined these factors into predictive models using stepwise selection.

DJK development up to 1 yr postoperative for CD-corrective surgery was predicted with high accuracy using only baseline demographic and clinical factors (AUC = 87%). The presence of comorbidities was one of the significant predictors of DJK in this model, with diabetes, hypertension, and depression being the most common comorbidities. Baseline neurological deficit
was another significant predictor of DJK in this demographic and clinical variables model, possibly resulting from changes in patients’ neurological function and balance maintenance that might lead to altered postural alignment. Additionally, preoperative C3-T3 angle was predictive of DJK in this model, which adds to the growing body of literature that preoperative sagittal malalignment contributes to the development of junctional kyphosis. Previous studies have shown that CD patients have a wide range of comorbidities and frailty indicators that put patients at risk for complications, which could contribute to the development of DJK.

DJK occurrence was predicted with high accuracy using only surgical variables (AUC = 81%). Combined approach surgeries were the strongest predictor of DJK in this model (OR: 7.9, CI: 1.7-37.1), which mirrors previous research on junctional kyphosis development. Studies have reported that surgical approach is an important consideration in minimizing junctional kyphosis. Other significant factors included posterior UIV below C4, transition rod use, more than 3 posterior osteotomies, and 3-column osteotomies, suggesting that altering the biomechanics of the spine influences stabilization of the spine and can lead to mechanical failure and DJK development.

Additionally, we did not find differences in clinical outcomes between patients with and without DJK, which is similar to results from adult spinal deformity literature on proximal junctional kyphosis, which showed no differences in clinical outcomes at early follow-up. Longer term follow-up on this cohort of patients is needed in order to better assess
demographic and clinical outcomes for patients with and without DJK.

Limitations

We appreciate several limitations to our study. Firstly, the retrospective nature of this study might limit the findings; however, since the patients were enrolled from many centers across the continental United States, this might increase the generalizability of our findings. There is significant variability in the baseline inclusion of CD, but all patients are operative and underwent specifically correction of their CD. A limitation that lies in the database, and with this current study, is that it is uncertain if our conclusions can be externally validated and generalized to a broader CD patient population due to a relatively heterogeneous population and small sample size, also contributing to a lack of power in large categorical variables. A limitation to the models created is that many variables were assigned to relatively few patients. It is possible that the model may suffer from overfitting, and as a result may not be generalizable to other patients. A larger sample size may help address this issue and should be validated in other CD populations. Secondly, there was no control group of CD patients who underwent nonoperative treatment, which potentially limits conclusions drawn in regards to outcomes. Additionally, there were no magnetic resonance imaging available for these CD surgical patients who assess any ligamentous or disc degeneration causes of DJK. This study also has limited granularity of neurological abnormalities for this cohort of patients.

CONCLUSION

There was a 23.1% prevalence of DJK in a cohort of 117 CD patients undergoing surgical correction. DJK was predicted with high accuracy using a combination of neurological, surgical, and primarily radiographic factors, most markedly 3-column osteotomy use, combined approach, TS-CL > 31° and cSVA > 54 mm. Preoperative assessment and consideration should be given to these factors that are predictive of DJK to mitigate poor outcomes.

Disclosures

The International Spine Study Group (ISSG) is funded through research grants from DePuy Synthes, and supported the current work. The authors have no personal, financial, or institutional interest in any of the drugs, materials, or devices described in this article. Dr Passias is a consultant to Zimmer Biomet, Medtronic, and SpineWave. Dr V Lafage has been paid for lectures given to Depuy Synthes, NuVasive, K2M, and Medtronic, and is a board member and shareholder in Nemaris Inc. Dr Smith has grants from DePuy Synthes during the conduct of the study; receives personal fees from Zimmer-Biomet, NuVasive, Cerapedics, and K2M; and has grants from AOSpine and NREF outside the submitted work. Dr Protopsaltis is a consultant to Medicrea, Breton Line, and ISSG, and is on the Scientific Advisory Board for Allosource. Dr Kelly received monetary paid to the University for research from DePuy Synthes, OREF, CSRS, AOSpine, Fox Family Foundation, and Barnes Jewish Foundation. Dr Klineberg is on the Board of Directors and is a Share holder in Nemaris Inc, and receives royalties from K2M and MSD. Dr Bess is a consultant for Allosource and K2M; receives royalties and research support from K2M, Innovaxis, and NuVasive; receives royalties from Pioneer; and receives research support from DePuy Synthes Spine and Stryker. Dr Shaffrey receives royalties from, has patents with, and consults for Medtronic, NuVasive, and Zimmer Biomet; is a stock holder in NuVasive; is a consultant to K2M, Stryker, and In Vivo; and has grants from the NIH, Department of Defense, ISSG, DePuy Synthes, and AO. Dr Ames receives consulting fees from DePuy Synthes, Medtronic, and Stryker; receives royalties from Zimmer Biomet; and has patents with Fish & Richardson, PC.

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