Patient-specific Cervical Deformity Corrections With Consideration of Associated Risk

Establishment of Risk Benefit Thresholds for Invasiveness Based on Deformity and Frailty Severity

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Study Design/Setting: This was a retrospective cohort study.

Background: Little is known of the intersection between surgical invasiveness, cervical deformity (CD) severity, and frailty.

Objective: The aim of this study was to investigate the outcomes of CD surgery by invasiveness, frailty status, and baseline magnitude of deformity.

Methods: This study included CD patients with 1-year follow-up. Patients stratified in high deformity if severe in the following criteria: T1 slope minus cervical lordosis, McGregor's slope, C2–C7, C2–T3, and C2 slope. Frailty scores categorized patients into not frail and frail. Patients are categorized by frailty and deformity (not frail/low deformity; not frail/high deformity; frail/low deformity; frail/high deformity). Logistic regression assessed increasing invasiveness and outcomes [distal junctional failure (DJF), reoperation]. Within frailty/deformity groups, decision tree analysis assessed thresholds for an invasiveness cutoff above which experiencing a reoperation, DJF or not achieving Good Clinical Outcome was more likely.

Results: A total of 115 patients were included. Frailty/deformity groups: 27% not frail/low deformity, 27% not frail/high deformity, 23.5% frail/low deformity, and 22.5% frail/high deformity. Logistic regression analysis found increasing invasiveness and occurrence of DJF [odds ratio (OR): 1.03, 95% CI: 1.01–1.05, $P=0.002$], and invasiveness increased with deformity severity ($P<0.05$). Not frail/low deformity patients more often met Optimal Outcome with an invasiveness index <63 (OR: 27.2, 95% CI: 2.7–272.8, $P=0.005$). An invasiveness index <54 for the frail/low deformity group led to a higher likelihood of meeting the Optimal Outcome (OR: 9.6, 95% CI: 1.5–62.2, $P=0.018$). For the frail/high deformity group, patients with a score <63 had a higher likelihood of achieving Optimal Outcome (OR: 4.8, 95% CI: 1.1–25.8, $P=0.033$). There was no significant cutoff of invasiveness for the not frail/high deformity group.

Conclusions: Our study correlated increased invasiveness in CD surgery to the risk of DJF, reoperation, and poor clinical success. The thresholds derived for deformity severity and frailty may enable surgeons to individualize the invasiveness of their procedures during surgical planning to account for the heightened risk of adverse events and minimize unfavorable outcomes.

Key Words: cervical deformity, frailty, alignment, correction, complications, invasiveness, realignment

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Cervical deformity (CD) severity has been linked to poor quality of life.[1–4] The correction of CD can provide moderate relief of both pain and disability with cost-utility benefits in the long term.[5] Despite the correction, many patients are still subject to higher rates of poor clinical outcomes.[6–9] Many studies have made progress in determining the preoperative factors and surgical components with an impact on outcomes in CD surgery.[6,10–18] A previous study determined an overall complication rate of 75.6% among the CD cohort and associated certain baseline radiographic and functional disability scores with increased incidence of overall complications.[6] Similarly, studies have sought ways to identify and stratify patients preoperatively to best mitigate complication risk.

One emerging stratification in CD surgery is frailty.[19–22] Frailty, a measure incorporating both preexisting comorbidities and functional status, has been previously correlated to adverse outcomes in surgery.[23] Furthermore, while frail patients have shown to experience greater improvement following CD corrective surgery, they also incur higher rates of major complications.[22] In addition, with the increasing rates of comorbidities and age in the CD population, an improved understanding around the intersection of a patient's CD and physiological frailty may influence treatment choices and outcomes. Because frailty does not progress uniformly in the population compared with age, assessing patient frailty before surgical intervention can inform and possibly alter the treatment choice. The addition of frailty in the planning and execution of operative approach is a step forward in the pursuit of individualized medicine, reduction of morbidity, and maximization of recovery potential.

Previous studies have examined these effects in the context of adult spinal deformity (ASD), but due to the relatively complex nature of CD, there is a lack of granularity regarding surgical outcomes for CD patients.[6,10,11,17,18,24,25] The current study will focus on the impact frailty, severity of deformity, and surgical invasiveness have on the outcomes of CD correction. We hypothesize that increased frailty, deformity, and surgical invasiveness will increase the likelihood of adverse events. Therefore, we further predict lower invasiveness will be needed in patients with increased frailty and/or baseline deformity.

METHODS

Data Source

This was a retrospective cohort study of a prospectively collected, multicenter database of operative CD patients enrolled from 2013–2018. Institutional review board approval was received at all 13 participating centers before patient enrollment, with full consent from every patient. The database required patients to be over the age of 18 and have radiographic evidence of CD, as previously defined by the presence of at least 1 of the following criteria on the preoperative imaging collected: cervical kyphosis (C2–C7 Cobb angle > 10 degrees), cervical scoliosis (C2–C7 coronal Cobb angle <10 degrees), C2–C7 sagittal vertical axis (cSVA) > 40 mm or chin-brow vertical angle > 25 degrees.[26–28] Patients included in the present study had preoperative and at least one-year postoperative radiographic and health-related quality of life (HRQL) data.

Data Collection, Radiographic, and HRQL Assessment

Demographic variables collected and assessed included sex, age, body mass index, and comorbidity burden, measured by the Charlson Comorbidity Index. Surgical and complication data was collected following surgical intervention and comprised of variables such as operative time, estimated blood loss, surgical approach, instrumentation, osteotomy type, number of levels fused, medical complications, revisions, intensive care unit stay, and total length of hospital stay.

HRQL questionnaires were collected preoperatively and at the 1-year follow-up time point. Those included the Neck Disability Index (NDI), Numeric Rating Scale Neck (NRS-Neck), Euro-Qol 5 Dimension (EQ-5D), and the modified Japanese Orthopedic Association (mJOA) metrics.

Full-length free-standing lateral spine radiographs were used to assess CD patients at baseline and follow-up intervals and analyzed with SpineView (ENSAM, Laboratory of Biomechanics, Paris, France).[12,29,30] Cervical radiographic parameters assessed included the T1 slope minus cervical lordosis (TS–CL: mismatch between T1 slope and cervical curvature), McGregor's slope, C2–C7 cervical lordosis (CL), C2–T3 Cobb angle, and C2 sagittal slope in this CD cohort.

Deformity Stratification

Severity was determined by the modifiers anchored to the mJOA in a recent paper by *Passias* and colleagues.[16] Patients were stratified in High Deformity (HighD) if meeting severe deformity criteria in one of the previously defined cervical parameters (Table 1).[16,31,32] Patients below each threshold were classified as Low Deformity (LowD). Radiographic parameters included in the invasiveness index are: TS–CL, cSVA, thoracic kyphosis (T4–T12 angle), and C7-S1 sagittal vertical axis (SVA).[29]

Frailty Stratification

Frailty scores were calculated based upon the modified CD Frailty Index described by Passias et al[19] (Table 2).

TABLE 1. Radiographic Thresholds Signifying High Baseline Deformity

Radiographic parameter	Severity threshold
C2–C7 SVA (cSVA) (mm)	> 80
C2–C7 lordosis (deg.)	< −21
C2–T3 (deg.)	< −35
C2-slope (deg.)	> 49
McGregor's slope (deg.)	< −12 or > 19

cSVA indicates cervical sagittal vertical axis.

Patients were categorized as either frail, with a frailty score of ≥ 0.3 or higher, or not frail with a score <0.3.

Frailty and Deformity Severity Categorization

Patients were categorized by their baseline frailty and deformity status. This placed patients into 1 of 4 possible frailty/deformity groups: (1) Not Frail and Low Deformity (Not Frail/LowD), (2) Not Frail and High Deformity (Not Frail/HighD), (3) Frail and Low Deformity (Frail/LowD), or (4) Frail and High Deformity (Frail/HighD).

Invasiveness Index Calculation

Invasiveness was calculated, according to the previously published criteria in Table 3, by the following point assignments: history of prior cervical surgery (3 points), anterior cervical discectomy and fusion (2 points per level), corpectomy (4 points per level), number of levels fused (1 point per level), implants (1 point per level), posterior decompressions (2 per level), Smith-Peterson osteotomy (2 points per level), 3-column osteotomy (8 points per level), fusion to the upper cervical spine (2 points), absolute change in TS–CL, cSVA, T4–T12 thoracic kyphosis (0.5 point per 1-degree change), and SVA (0.5 point per 1 mm change) from baseline to 3-month follow-up.[29]

Definition of Outcomes

The minimally clinically important difference (MCID) for the mJOA was set at 1.8 based on published values.[15] The MCID for the NDI was set as 15; this is double the published MCID value because our NDI score was collected on a 0–100 scale as opposed to 0–50).[15] The NRS-Neck MCID was set as 2.5 per previously published values.[15] Virk et al[13] defined "Good Clinical Outcome" criteria as meeting 2 or more of the following: (1) an NDI score <20 or meeting MCID in NDI by 2 years, (2) mild myelopathy (mJOA score ≥ 14 by 2 y), (3) an NRS-Neck score ≤ 5 or improved by 2 or more points from baseline by 2 years. Optimal Outcome was defined as meeting Good Clinical Outcome, not undergoing reoperation, and not developing a distal junctional failure (DJF) by 2 years (Table 4). Distal junctional failure (DJF), also termed severe DJK, was defined as a DJK angle > 20 degrees AND a change in the DJK angle > 20 degrees from baseline to 2 years OR DJK deemed "catastrophic" by a consensus of surgeons within the study group.[34]

TABLE 2. Factors Included Within the Modified Cervical Deformity Frailty Index

Comorbidities
BMI < 18.5 or > 30 kg/m^2
Lung disease
Diabetes
Rheumatoid arthritis
Liver disease
Venous disease
Depression
> 4 comorbidities
Symptoms
Unsteady gait
Leg weakness
Bowel incontinence
Bladder incontinence
Patient-reported outcome
Anxiety (EQ-5D)
Difficulty sleeping > 6 h (SWAL-QOL)
Inability to walk (EQ-5D)

BMI indicates body mass index; EQ-5D, Euro-Qol 5 Dimension; SWAL-QOL, swallowing quality of life questionnaire.

TABLE 3. Surgical and Radiographic Components Used to Calculate the Cervical Deformity Invasiveness Score

Surgical factors	Points assigned
ACDF	2 points per level
Corpectomy	4 points per level
Levels fused	1 point per level
Implants	1 point per implant
Posterior decompression	2 points per level
Smith-Peterson osteotomy	2 points per level
Three-column osteotomy	8 points per level
Fusion to upper cervical spine	2 points
Revision status	3 points
Radiographic factors	
Absolute change in cSVA	0.5 point per 1 mm change
Absolute change in TS–CL	0.5 point per 1-degree change
Absolute change in thoracic kyphosis	0.5 point per 1-degree change
Absolute change in SVA	0.5 point per 1 mm change

ACDF indicates anterior cervical discectomy and fusion; cSVA, cervical sagittal vertical axis; SVA, sagittal vertical axis; TS−CL, T1 slope minus cervical lordosis.

Statistical Analysis

We used analysis of covariance to assess differences in demographics, surgical details, radiographic parameters, and outcome measures, utilizing the Gaines-Howell statistic when accounting for variability between groups. Binary logistic regression analysis assessed the relationship between increasing invasiveness and deformity with the occurrence DJF, reoperation, meeting Good Clinical Outcome at 2 years, and achieving Optimal Outcome in the overall cohort. Invasiveness scores were calculated within the frailty/deformity groups. Binary logistic regression analysis assessed the relationship between increasing invasiveness and experiencing an Optimal Outcome within each frailty/deformity group. Conditional inference tree analysis assessed a significant cutoff point, assessing the threshold for invasiveness scores leading to significantly higher rates of Optimal Outcome for each group. Univariate logistic regression assessed the relationship between invasiveness above significant cut-offs and the odds of each outcome. Decision tree analysis was conducted using the R statistical software package (R, version 3.2.4; R Foundation for Statistical Computing, Vienna, Austria). Descriptive, univariate, and regression analyses were performed using SPSS software (v25.0; IBM Corp., Armonk, NY). All significance was set to P-value <0.05.

TABLE 4. 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 2 of the 3: (1) an NDI score <20 or meeting MCID in NDI (2) mild myelopathy (mJOA score ≥ 14) (3) an NRS-Neck score ≤ 5 or improved by 2 or more points from baseline
Optimal Outcome	Meeting all 4: (1) Meeting Good Clinical Outcome (2) No occurrence of DJF (3)No occurrence of mechanical complication (4) No reoperation

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

RESULTS

Baseline Patient Characteristics

A total of 115 CD patients who underwent corrective procedures were included. As depicted for each group in Table 5, the overall cohort had a mean age of 61.1 ± 10.0 years, with 66% of the patients as female, an average body mass index was 28.8 ± 7.7 kg/m^2, baseline NDI mean score of 47.5 ± 17.7, mean mJOA score of 13.7 ± 2.7, mean Charlson Comorbidity Index total score of 0.9 ± 1.3, and mean modified CD Frailty Index of 0.3 ± 0.2. The cohort's mean radiographic profile was as follows: T1 slope: 31.7 ± 21.6 degrees; TS–CL: 37.8 ± 19.9 degrees; CL C2–C7: −6.1 ± 21.3 degrees; C2–T3: −17.6 ± 23.3 degrees; SVA C2–C7: 39.0 ± 19.3 mm; C2 slope: 37.6 ± 20.6 degrees; SVA C7-S1: 0.5 ± 69.6 mm. Although different in baseline frailty and all radiographic parameters except for T1 slope (range: 30.0–32.6 degrees, $P = 0.949$), there were no differences seen in demographics across all 4 groups (all $P < 0.1$).

Surgical Overview

According to the surgical approach, 19.1% of patients underwent anterior-only procedures, 47.0% posterior-only, and 33.9% combined anterior-posterior surgeries. The mean number of levels fused was 7.6 ± 3.9 with a mean International Spine Study Group (ISSG) invasiveness score of 62.9 ± 26.4. The average operative time was 390 ± 228 minutes, with an estimated blood loss of 823 ± 860 mL, and postoperative length of stay of 6.9 ± 7.9 days, with 83.5% of the cohort experiencing any osteotomy (17% 3-column osteotomies). There were

TABLE 5. Cohort Demographics, Surgical Details, and Radiographic Parameters

	Mean ± SD				
	Frailty/deformity status				
Characteristic	Not frail/low deformity (n = 31)	Not Frail/high deformity (n = 31)	Frail/low deformity (n = 27)	Frail/high deformity (n = 26)	P
Demographics					
Age (y)	62.8 ± 8.8	62.3 ± 8.9	58.3 ± 10.8	60.4 ± 11.7	0.322
Sex (female) (%)	58	55	74	81	0.117
BMI (kg/m^2)	26.6 ± 5.8	28.6 ± 5.0	30.3 ± 8.5	30.1 ± 10.6	0.233
CCI	0.9 ± 1.1	0.7 ± 1.0	1.2 ± 1.8	1.0 ± 1.3	0.484
Frailty	0.20 ± 0.10	0.20 ± 0.10	0.47 ± 0.14	0.49 ± 0.16	< 0.001
Osteoporosis (%)	10	16	22	15	0.640
Surgical details					
Operative time (min)	385 ± 184	387 ± 244	431 ± 275	359 ± 212	0.723
EBL (mL)	851 ± 937	967 ± 1083	767 ± 648	678 ± 652	0.632
Levels fused	6.9 ± 3.9	8.4 ± 4.4	7.4 ± 2.7	7.8 ± 4.2	0.472
Approach					
Anterior	29	13	15	19	0.349
Posterior	42	48	41	58	
Combined	29	39	44	23	
Osteotomy (%)	90	87	78	77	0.433
Major osteotomy (%)	29	19	7	12	0.141
Decompression (%)	58	42	67	54	0.296
Invasiveness	54.9	70.3	59.4	67.1	0.091
SICU admission	52	74	70	65	0.273
LOS (d)	4.4 ± 2.5	7.0 ± 4.3	8.5 ± 11.9	8.0 ± 9.9	0.193
Radiographic parameters (deg.)					
T1 slope (deg.)	32.2 ± 17.2	32.6 ± 17.5	30.0 ± 15.3	31.7 ± 21.6	0.949
Cervical lordosis (deg.)	3.5 ± 18.6	−16.4 ± 22.3	3.2 ± 15.4	−15.1 ± 19.6	< 0.001
TS–CL (deg.)	28.7 ± 7.7	49.0 ± 23.0	26.7 ± 10.0	46.8 ± 22.8	< 0.001
C2 slope (deg.)	27.5 ± 8.1	49.6 ± 24.2	26.4 ± 10.5	47.0 ± 22.5	< 0.001
C2–T3 (deg.)	−4.1 ± 14.7	−30.2 ± 21.6	−2.7 ± 14.4	−31.4 ± 23.6	< 0.001
cSVA (mm)	36.4 ± 19.1	46.7 ± 18.3	29.9 ± 14.1	42.4 ± 21.8	0.005

BMI indicates body mass index; CCI, Charlson Comorbidity Index; cSVA, cervical sagittal vertebral Axis; EBL, estimated blood loss; LOS, length of stay; SICU, surgical intensive care unit; TS−CL, T1 slope minus cervical lordosis.

TABLE 6. Outcomes by Frailty/Deformity Groups

Frailty/ deformity group	Mean invasiveness	Rate of DJF (%)	Rate of major complication (%)	Rate of revision (%)	Rate of meeting Good Clinical Outcome (%)	Rate of achieving Optimal Outcome (%)
Not frail/low deformity	54.9	3.2	16.1	20.7	71.0	58.1
Not frail/high deformity	70.3	25.8	22.6	26.7	80.7	41.9
Frail/low deformity	59.4	14.8	37.0	7.4	74.1	63.0
Frail/high deformity	67.1	15.4	23.1	12.0	53.9	42.3
Total	62.3	14.3	23.5	16.5	69.8	51.3

DJF indicates distal junctional failure.

no differences seen in surgical details across all 4 groups (all $P<0.05$).

Frailty and Deformity Severity Grouping

Through categorization of deformity at baseline, 50.5% met the criteria for the low deformity group, while 49.5% had High Deformity. Baseline frailty placed 54.0% of patients into the Not Frail group, and 46.0% as Frail. This categorized the patients into frailty/deformity groups as follows: 27.0% in Not Frail/LowD, 27.0% in Not Frail/HighD, 23.5% in Frail/LowD, and 22.5% in Frail/HighD. There was no single site in the database that contributed over 25% to any one grouping's composition.

Increasing Deformity and Outcomes

Baseline radiographic parameters for each group are presented in Table 5. Binary logistic regression analysis did not find a significant relationship between increasing baseline deformity severity and occurrence of DJF, reoperation, meeting Good Clinical Outcome, or Optimal Outcome by 2 years (all $P<0.05$).

Increasing Invasiveness and Outcomes

In Table 6, invasiveness increased with deformity severity but was not statistically significant: 54.9 Not Frail/LowD, 70.3 Not Frail/HighD, 59.4 Frail/LowD, 67.1 Frail/HighD; ($P=0.091$). There was also no significant relationship found between increasing invasiveness and the occurrence of reoperation or meeting Good Clinical Outcome. A weakly significant relationship was found between increasing invasiveness and occurrence of DJF [odds ratio (OR): 1.03, 95% CI: 1.01–1.05, $P=0.002$] and meeting Optimal Outcome (OR: 0.98, 95% CI: 0.97–0.99, $P=0.017$).

Outcomes by Frailty/Deformity Groups

The outcomes for each frailty/deformity group are conveyed in Table 6. Not frail patients with high deformity had the highest rate of DJF (25.8%) and reoperation (26.7%), as well as the highest rate of meeting Good Clinical Outcome by 2 years (80.7%). After defining an Optimal Outcome as meeting a Good Clinical Outcome without the development of DJF or reoperation by 2 years, 51.3% met this outcome overall. By grouping, 58.1% of the Not Frail/LowD patients met Optimal Outcome, 41.9% of the Not Frail/HighD, 63.0% of the Frail/LowD, and 42.3% of the Frail/HighD. These rates were not significantly different between groupings ($P=0.271$).

Invasiveness Cutoffs for Frailty/Deformity Groups

The mean invasiveness index scores for those who did or did not achieve Optimal Outcome are displayed in Table 7. Not Frail patients had significantly higher invasiveness scores when experiencing an unfavorable outcome (55.6 vs. 69.6, $P=0.032$), and the same was seen for low deformity patients at baseline (50.0 vs. 67.6, $P=0.001$). Overall, invasiveness scores were lower for those achieving Optimal Outcome (56.6 vs. 68.3, $P=0.014$).

Conditional inference tree analysis derived thresholds for meeting Optimal Outcome within each frailty/deformity group, as seen in Table 8. Not Frail/LowD patients more often met Optimal Outcome with an invasiveness index <63 (OR: 27.2, 95% CI: 2.7–272.8, $P=0.005$). An invasiveness index <54 for the Frail/LowD group led to a higher likelihood of meeting Optimal Outcome (OR: 9.6, 95% CI: 1.5–62.2, $P=0.018$). For the Frail/HighD, patients with an invasiveness cutoff score <63 had a higher likelihood of achieving Optimal Outcome (OR: 4.8, 95% CI: 1.1–25.8, $P=0.033$). However, there was no significant cutoff of invasiveness for the Not Frail/HighD group.

DISCUSSION

The present study categorized patients by frailty and CD severity to gain a greater understanding on the impact

TABLE 7. Invasiveness Score for Achieving Optimal Outcome by Frailty and Deformity Groups

	Mean ± SD		
Frailty category	Did not meet Optimal Outcome	Met Optimal Outcome	*P*
Not frail	69.6 ± 26.4	55.6 ± 24.0	0.032
Frail	69.3 ± 24.4	57.7 ± 28.5	0.119
Low deformity	67.6 ± 20.8	50.0 ± 17.2	0.001
High deformity	70.7 ± 28.2	66.2 ± 33.3	0.579
Overall	68.3 ± 25.7	56.6 ± 25.6	0.014

TABLE 8. Deformity and Invasiveness Relationship With Outcomes Via Odds Ratio

	Odds ratio (95% CI)	P
Increasing invasiveness		
DJF	1.03 (1.01–1.05)	0.002
Reoperation	1.01 (0.99–1.03)	0.223
Good Clinical Outcome	1.0 (0.98–1.01)	0.667
Optimal Outcome	0.98 (0.97–0.99)	0.017
Invasiveness threshold of 63 for not frail/low deformity		
DJF	*	< 0.001
Reoperation	0.14 (0.02–0.99)	0.049
Good Clinical Outcome	12.7 (2.0–80.1)	0.007
Optimal Outcome	27.2 (2.7–272.8)	0.005
Invasiveness threshold of 72 for not frail/high deformity		
DJF	0.15 (0.02–0.91)	0.039
Reoperation	0.69 (0.14–3.52)	0.658
Good Clinical Outcome	1.6 (0.6–4.1)	0.636
Optimal Outcome	2.3 (0.5–10.1)	0.288
Invasiveness threshold of 54 for frail/low deformity		
DJF	0.3 (0.0–2.9)	0.268
Reoperation	0.9 (0.1–16.5)	0.957
Good Clinical Outcome	3.8 (0.6–24.3)	0.165
Optimal Outcome	9.6 (1.5–62.2)	0.018
Invasiveness threshold of 63 for frail/high deformity		
DJF	*	< 0.001
Reoperation	*	< 0.001
Good Clinical Outcome	2.0 (0.4–9.8)	0.394
Optimal Outcome	4.8 (1.1–25.8)	0.033

The * refers to unavailable values.
DJF indicates distal junctional failure.

invasiveness may have in the surgical outcomes of each group. Given that varying iterations of frailty and deformity are relatively under-investigated in this population, we found higher invasiveness less often led to the Optimal Outcome overall, and lower degrees of invasiveness were needed to achieve favorable outcomes in high frailty and high baseline deformity states.

Previous studies have examined characteristics of CD correlating to increased rates of complications following corrective surgery. Passias et al[12] created a predictive model for overall poor outcomes following CD surgery, where 4 of the 6 predictors were radiographic. Similarly, a study found a significant correlation between preoperative severity in cSVA and the occurrence of any complication.[6] In addition, the study found CD descriptors were predictors of medical complications. More recently, a study found a correlation between TS−CL, C2–T3, and C2 slope and postoperative complications, such as reoperation and mortality after CD surgery.[6] The current study examined CD by classifying a severe designation in any 1 of 5 radiographic parameters as high deformity. Increasing deformity severity was not significantly associated with DJF, reoperations, not meeting Good Clinical Outcome criteria, or achieving Optimal Outcome in the overall cohort. This specific categorization of deformity may, in fact, reinforce the notion that certain individual parameters have a better association with complication rates after surgery, serving as possible guides for physicians during surgical planning to minimize adverse outcomes rather than utilizing severe deformity overall.

Invasiveness was the third factor studied for its effect on the development of poor outcomes following CD surgery at the intersection of frailty and deformity. Like the current study, invasiveness has also been correlated to increased rates of postoperative complications in ASD surgery.[25,34] A study analyzing the effect of invasiveness in ASD surgery by frailty correlated the likelihood of major complications and reoperations with increased invasiveness, along with the incidence not meeting a favorable outcome.[25] Upon logistic regression and CIT analysis, the authors further derived invasiveness thresholds for each frailty category, generating a threshold of 63.9 for their cohort overall.[25] Likewise, we identified a relationship between increasing invasiveness and the development of DJF by 2 years. While the invasiveness index used in the current study was originally correlated to the risk of higher estimated blood loss, operative time, and length of stay, we believe this is the first study correlating overall invasiveness to postoperative complications in CD surgery.[29] This finding is just a window into the influence that invasiveness may have on the outcomes in the CD population.

Finally, we examined invasiveness in the context of both frailty and deformity. Our results identified utilizing an invasiveness score lower than the derived thresholds led to significant increases in achieving the Optimal Outcome. Few studies have correlated characteristics of invasiveness to postoperative complications in this population. Construct length has been shown to increase rates of poor outcomes following CD correction, although the current literature has warranted future studies to examine this across the magnitude of deformity.[29,35] When stratifying by severity of deformity, logistic regression showed increasing invasiveness trended towards lower rates of meeting Optimal Outcome, although less so in frail with high deformity, and not at all in not frail with high deformity. Therefore, in certain instances, more invasive procedures may be needed to address higher degrees of deformity, and the clinical benefit achieved from higher invasiveness scores may outweigh the risk of postoperative complications, although the evidence promoting this claim was demonstrated in a small cohort with an overall low rate of ideal outcomes, possibly leading to the lack of statistical cutoff in invasiveness. To our knowledge, while being the first study to describe the effect of invasiveness on poor long-term outcomes in CD, these results also attempt to fill the aforementioned gap by identifying the interaction between CD and invasiveness.

The lower invasiveness thresholds seen in those with increased frailty and deformity, relative to the not frail cohort, best summates the interplay between these 3 characteristics. Our study was underpowered to render strong clinical recommendations regarding the interventions effective in treating frail patients with high deformity, future endeavors should further examine the effects of varying techniques and realignment strategies on clinical improvement versus increased perioperative risk in this delicate population. Yet, given the multicenter nature and broad clinical variation inherent to the data, with respect to surgical invasiveness, deformity, and frailty, we believe these findings can provide integral value to surgical planning in conventional practice and a springboard into investigations further into this topic to potentially decrease the occurrence of unfavorable outcomes in CD corrective surgery.

At the same time, we acknowledge several limitations. Foremost, as a retrospective study, the data used in this investigation is subject to selection, indication and expertise bias. We cannot ascertain the extent to which inherent measures of frailty or deformity severity already modulated surgeon approaches when making decisions regarding surgical approaches at the point of care. In addition, we were unable to provide the indication for each surgery. Because the CD population is heterogenous, we encourage future studies to analyze our results in the context of unique diagnoses to better suit our conclusions to the patient. Thus, we recognize that our findings should be investigated further in other study sets, especially with respect to the durability of the frailty threshold we have generated. Second, follow-up approximates 1-year postoperative in most instances and there is the potential for additional adverse events, such as reoperations and functional deterioration to occur beyond this time point. Third, the sample size—while relatively large as compared with other studies on this topic—may still allow for restricted event rates and limited power, especially when looking at interactions between covariates. That being said, this analysis was performed on the largest existing prospective database of adult CD patients. Outcomes could potentially be different in other clinical settings and this reinforces our previous call for future work to independently validate the results presented here.

CONCLUSIONS

Our study correlated increasing invasiveness to DJF, reoperation, and achieving a favorable clinical outcome in CD surgery. Furthermore, lower invasiveness scores needed to achieve an Optimal Outcome were seen in the frail population. Specific invasiveness thresholds may personalize the surgical planning for patients with varying degrees of frailty and deformity to minimize unfavorable outcomes following the correction of CD.

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