Spine Deformity
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CASE SERIES

Expectations of clinical improvement following corrective surgery for adult cervical deformity based on functional disability at presentation

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Abstract

Purpose To assess impact of baseline disability on HRQL outcomes.

Methods CD patients with baseline (BL) and 2 year (2Y) data included, and ranked into quartiles by baseline NDI, from lowest/best score (Q1) to highest/worst score (Q4). Means comparison tests analyzed differences between quartiles. ANCOVA and logistic regressions assessed differences in outcomes while accounting for covariates (BL deformity, comorbidities, HRQLs, surgical details and complications).

Results One hundred and sixteen patients met inclusion (Age:60.97 ± 10.45 years, BMI: 28.73 ± 7.59 kg/m^2, CCI: 0.94 ± 1.31). The cohort mean cSVA was 38.54 ± 19.43 mm and TS-CL: 37.34 ± 19.73. Mean BL NDI by quartile was: Q1: 25.04 ± 8.19, Q2: 41.61 ± 2.77, Q3: 53.31 ± 4.32, and Q4: 69.52 ± 8.35. Q2 demonstrated greatest improvement in NRS Neck at 2Y (−3.93), compared to Q3 (−1.61, $p = .032$) and Q4 (−1.41, $p = .015$). Q2 demonstrated greater improvement in NRS Back (−1.71), compared to Q4 (+0.84, $p = .010$). Q2 met MCID in NRS Neck at the highest rates (69.9%), especially compared to Q4 (30.3%), $p = .039$. Q2 had the greatest improvement in EQ-5D (+0.082), compared to Q1 (+0.073), Q3 (+0.022), and Q4 (+0.014), $p = .034$. Q2 also had the greatest mJOA improvement (+1.517), $p = .042$.

Conclusions Patients in Q2, with mean BL NDI of 42, consistently demonstrated the greatest improvement in HRQLs whereas those in Q4, (NDI 70), saw the least. BL NDI between 39 and 44 may represent a disability "Sweet Spot," within which operative intervention maximizes patient-reported outcomes. Furthermore, delaying intervention until patients are severely disabled, beyond an NDI of 61, may limit the benefits of surgery.

Keywords Cervical spine · Cervical deformity surgery · Clinical improvement

Introduction

Adult cervical deformity (CD) constitutes a subset of abnormal spinal morphology of multifactorial etiology, and is anticipated to increase in prevalence in the coming decades [1, 2]. In CD patients who fail non-operative management, operative intervention is generally accepted as an effective modality.

Without operative intervention, CD patients often experience radiographic progression of deformity over time, which subsequently translates into reduced Health-Related Quality of Life (HRQL) [3, 4]. Symptomatic CD patients also experience faster declines in HRQL metrics compared to the general population [5]. Even following optimal technical correction of adult deformity, a number of patients will experience suboptimal clinical results [6]. While the etiology behind such events is likely multifactorial [7], understanding the influence of baseline disability is important, as surgeons must balance the potential for patients to benefit from CD surgery against the prospect of complications, adverse events and clinical deterioration were surgery to be delayed.

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In this context, there is a lack of consensus around the degree of baseline deformity and disability that should trigger consideration for surgical intervention [8–10]. Given the substantial risks and costs associated with CD surgery [11], identifying patients most likely to benefit from operative intervention is of clear clinical importance. As such, we sought to understand associations between baseline disability and post-operative improvement in patient-reported outcomes in patients with CD. This study relied on a large dataset, with broad clinical variation, that has been used in the past to evaluate various aspects of spinal deformity surgery [7, 12]. Based on prior experience, we hypothesized that patients with greater baseline disability would demonstrate enhanced improvement in HRQL following CD-corrective surgery until reaching a threshold of diminishing returns.

Materials and methods

Study design and setting

The International Spine Study Group comprises 13 distinct centers across the United States, contributing consecutively enrolled, consented patient data with Institutional Review Board approval to a prospectively-enrolled Adult Cervical Deformity (CD) database that the present study utilized via retrospective analysis. Database enrollment criteria consisted of patients ≥ 18 years of age with a minimum of one of the following radiographic measures: Cervical Kyphosis (C2–C7 Cobb Angle $> 10°$), C2–C7 Sagittal Vertical Axis (cSVA) > 4 cm, Chin-Brow Vertical Angle (CBVA) $> 25°$, or T1 slope minus Cervical Lordosis (TS-CL) > 10.

Inclusion and exclusion criteria

Operative CD patients with baseline and 2-year radiographic and health related quality of life (HRQL) data were included for analysis.

Data collection and radiographic parameters

Demographic data collected consisted of patient age, sex, body mass index (BMI), and Charlson Comorbidity Index (CCI). Surgical parameters included: levels fused, length of stay, operative time, blood loss, decompressions, surgical approach, and osteotomies etc. Patient reported outcome measures collected at baseline and follow-up visits were Neck Disability Index (NDI), modified Japanese Orthopaedic Association scale (mJOA), Numeric Rating Scale (NRS) for neck and back pain, and EuroQuol-5D (EQ-5D) questionnaire. Improvement in outcomes was evaluated on a continuous basis as well as via minimal clinically importance difference (MCID) thresholds based on published values in the literature [13, 14].

Full length free-standing lateral spine radiographs (EOS or 36-inch cassette if unavailable) were collected and assessed at baseline and follow-up. Radiographic images were analyzed using SpineView® (ENSAM, Laboratory of Biomechanics, Paris, France) software according to previously published validated and standardized techniques [15–17].

Cohort stratification and statistical analysis

The cohort was stratified by baseline NDI score into quartiles (Q1–Q4), with those in Q1 having the lowest baseline NDI scores (i.e., least disabled) and those in Q4 having the highest baseline NDI scores (i.e., most disabled). One-way analysis of variance (ANOVA) assessed group differences in demographic, surgical, radiographic factors, and HRQL metrics at baseline and 2 years. When analyzing HRQL outcomes in a binary fashion (improved by ≥ 1 MCID vs. < 1 MCID), stepwise logistic regression analyses were utilized to generate odds ratios for 2 year HRQL outcomes across disability groups Q1–Q3 with respect to Q4. All analyses adjusted for covariates including age at presentation, baseline deformity and realignment at 6 weeks post-op, surgical invasiveness, major complications, and reoperations. In addition, for each primary HRQL outcome, logistic regression included the respective baseline HRQL scores as a covariate to account for regression to the mean. All statistical analyses were performed using SPSS Version 25 (Armonk, NY), with statistical significance defined for all tests as p value < 0.05.

Results

Baseline demographics of the cohort and disability quartiles

One hundred and sixteen patients met inclusion criteria. The mean patient age was 61.0 ± 10.4 years, with a mean BMI of 28.7 kg/m^2 ± 7.6, mean CCI of 0.9 ± 1.3, and mean frailty of 0.4 ± 0.1. The cohort was 63.8% female. While BMI, CCI, and gender composition was similar across disability quartiles, baseline age and frailty were significantly different (both $p < 0.001$). Patients in Q4 (55.7 ± 10.5 years) were significantly younger than Q1 (65.8 ± 8.5 years) and Q2 (63.8 ± 10.1 years), yet those in Q4 (0.5 ± 0.1) were significantly more frail than Q1 (0.3 ± 0.1) and Q2 (0.4 ± 0.1), Table 1.

Table 1 Demographics by Disability Quartile

Demographics	Q1	Q2	Q3	Q4	*p* values
N	29	25	29	33	–
Age (Years)	65.8 ± 8.5	63.8 ± 10.1	59.7 ± 9.9	55.7 ± 10.5	< .001
Gender (% Female)	48.3%	60.0%	72.4%	72.7%	> .05
BMI (kg/m^2)	26.9 ± 5.1	29.9 ± 6.4	28.6 ± 9.0	29.5 ± 9.0	> .05
CCI	0.8 ± 1.3	1.4 ± 1.14	0.8 ± 1.4	0.8 ± 1.3	> .05
CD-FI	0.3 ± 0.1	0.4 ± 0.1	0.5 ± 0.1	0.5 ± 0.1	< .001

Demographics by Disability Quartile, *Q1* Quartile 1, *Q2* Quartile 2, *Q3* Quartile 3, *Q4* Quartile 4
BMI Body Mass Index, *CCI* Charlson Comorbidity Index, *CD-FI* Cervical Deformity Frailty Index

Table 2 Baseline HRQLs by Disability Quartile

Baseline HRQLs	Q1	Q2	Q3	Q4	*p* values
NDI	25.0 ± 8.2	41.6 ± 2.8	53.3 ± 4.3	69.5 ± 8.4	< .001
mJOA	14.5 ± 2.6	14.7 ± 2.6	12.9 ± 2.9	12.7 ± 2.4	.009
NRS neck	4.8 ± 2.8	6.5 ± 2.4	7.0 ± 1.8	8.4 ± 1.3	< .001
NRS back	3.8 ± 2.9	4.2 ± 2.8	5.6 ± 2.8	6.2 ± 3.2	.005
EQ-5D-3L	0.8 ± 0.0	0.8 ± 0.1	0.7 ± 0.1	0.7 ± 0.0	< .001

Baseline HRQLs by Disability Quartile, *Q1* Quartile 1, *Q2* Quartile 2, *Q3* Quartile 3, *Q4* Quartile 4

NDI neck disability index, *mJOA* modified japanese orthopaedic association scale, *NRS* numeric rating score, *EQ-5D-3L* EQ-5D three-levels

Baseline HRQLs of the cohort and disability quartiles

Mean baseline NDI of the cohort was 48.3 ± 18.0. After patients were grouped into disability quartiles, the mean baseline NDI of Q1 ($N = 29$) was 25.0 ± 8.2, 41.6 ± 2.8 for Q2 ($N = 25$), 53.3 ± 4.3 for Q3 ($N = 29$), and 69.5 ± 8.4 for Q4 ($N = 33$). Patients in Q1 had a baseline NDI scores up to 36 whereas scores of Q2 ranged from 38 to 46, scores of Q3 ranged from 48 to 60, and scores of Q4 ranged from 62 to 92. At baseline, the cohort had a mean mJOA of 13.6 ± 2.7, NRS Neck of 6.7 ± 2.5, NRS Back of 6.2 ± 3.2, and EQ-5D-3L of 0.7 ± 0.1. All HRQL scores were significantly different between disability quintiles, all p values < 0.009. Patients in Q4 (12.7 ± 2.4) had significantly worse baseline mJOA scores than those in Q1 (14.5 ± 2.6) and Q2 (14.7 ± 2.6). Similarly, patients in Q4 (8.4 ± 1.3) had significantly worse baseline NRS Neck Scores than those in Q1 (4.8 ± 2.8) and Q2 (6.5 ± 2.4). In contrast, patients in Q1 had significantly better baseline NRS Neck Scores than all other groups. With respect to NRS Back, patients in Q1 (3.8 ± 2.9) scored the best, however only significantly better than those in Q4 (6.2 ± 3.2). Finally, patients in Q1 (0.8 ± 0.0) scored better than all other groups with respect to baseline EQ-5D-3L and those in Q4 (0.7 ± 0.1) scored worse than all other groups in EQ-5D-3L, Table 2.

Baseline deformity of the cohort and disability quartiles

Radiographically, the entire cohort presented with a mean cSVA of 38.5 mm ± 19.4, TS-CL of 37.3° ± 19.7, and C2 Slope of 36.9° ± 20.3. Furthermore, 54.3% of patients had a baseline cSVA modifier of 0, 8.6% had a baseline TS-CL modifier of 0, and 18.8% had a baseline horizontal gaze modifier of 0. Despite demographic differences, there were no significant differences in baseline CD between disability quartiles, Table 3.

Surgical details of cohort and disability quartiles

The cohort had a mean estimated blood loss of 768 ± 821 mL, mean operative time of 374 ± 221 min, and a mean of 8 ± 3 levels fused. By approach type, 19.8% of patients underwent an anterior approach, 45.7% had a posterior-only approach, and 34.5% had a combined approach. Furthermore, 53.5% of patients underwent decompression and 48.3% of patients underwent osteotomy. Finally, 12.1% had major complications, 16.4% had minor complications and 5.2% of patients required reoperation. Major and minor complication designation was done according to previously published criteria [18]. Between disability quartiles, there were no differences in levels fused, rates of osteotomy, decompression, surgical approach, EBL, or operative times between groups. In addition, while rates of reoperation and minor complications were similar between disability groups, those in Q3 (27.6%) had significantly higher rates of major complications compared to those in Q4 (3.0%) {$p = 0.015$}.

2-Year HRQLs of the cohort and disability quartiles

At 2 year follow-up, the mean mJOA of the cohort was 14.3 ± 3.2, mean NRS Neck was 4.0 ± 3.0, mean NRS Back was 4.6 ± 3.1, and mean EQ-5D was 0.8 ± 0.1. All HRQL scores were significantly different between disability quartiles (all p values < 0.009). Compared to those in Q4 (12.9 ± 3.5), those in Q1 (15.3 ± 2.2) and Q2 (15.2 ± 3.1) had significantly better 2 year mJOA scores ($p = 0.013$ and

Table 3 Baseline Deformity by Disability Quartile

Baseline deformity	Q1	Q2	Q3	Q4	*p* value
cSVA (mm)	36.6 ± 20.3	40.4 ± 17.1	36.8 ± 17.2	40.3 ± 22.5	> .05
TS-CL (°)	35.0 ± 20.1	40.4 ± 21.7	35.0 ± 12.8	39.2 ± 22.9	> .05
C2 Slope (°)	34.0 ± 20.2	40.1 ± 22.1	34.3 ± 14.5	39.2 ± 23.4	> .05
SVA (mm)	−11.7 ± 57.2	−1.7 ± 61.6	5.1 ± 68.4	10.4 ± 84.0	> .05
PI-LL (°)	−0.7 ± 17.5	3.4 ± 15.7	2.2 ± 18.3	0.4 ± 20.7	> .05
PT (°)	19.0 ± 12.7	21.5 ± 9.9	20.1 ± 10.0	19.0 ± 11.8	> .05
Ames modifiers					
cSVA modifier	Q1	Q2	Q3	Q4	*p* value
0	58.6%	60.0%	51.7%	48.5%	> .05
+	41.1%	40.0%	48.3%	51.5%	> .05
+ +	0.0%	0.0%	0.0%	0.0%	> .05
TS-CL modifier	Q1	Q2	Q3	Q4	*p* value
0	10.3%	8.0%	3.4%	12.1%	> .05
+	10.3%	8.0%	3.4%	26.1%	> .05
+ +	79.3%	84.0%	93.1%	81.8%	> .05
Horizontal modifier	Q1	Q2	Q3	Q4	*p* value
0	24.1%	16.0%	19.2%	15.6%	> .05
+	41.4%	48.0%	53.8%	40.6%	> .05
+ +	34.5%	36.0%	26.9%	43.8%	> .05
mJOA modifier	Q1	Q2	Q3	Q4	*p* value
None	15.4%	19.0%	4.0%	0.0%	> .05
Mild	42.3%	38.1%	32.0%	28.1%	> .05
Moderate	26.9%	28.6%	36.0%	43.8%	> .05
High	15.4%	14.3%	28.0%	28.1%	> .05

Baseline Deformity by Disability Quartile *Q1* Quartile 1, *Q2* Quartile 2, *Q3* Quartile 3, *Q4* Quartile 4

cSVA C2-C7 Sagittal Vertical Axis, *TS-CL* T1 Slope Minus Cervical Lordosis, *mJOA score* modified Japanese Orthopaedic Association score

$p = 0.032$ respectively). With respect to NRS Neck scores at 2 years, those in Q1 (2.3 ± 2.1) and Q2 (2.8 ± 2.4) scored significantly better than those in Q3 (4.8 ± 2.7) and Q4 (5.7 ± 3.1) {all $p < 0.005$}.

With respect to NRS Back scores at 2 years, patients in Q1 (3.5 ± 3.0) scored significantly better than those in Q4 (6.6 ± 2.6), whereas those in Q2 (2.9 ± 2.2) scored significantly better than those in Q3 (5.0 ± 3.1) and Q4 (all $p < 0.031$). Finally, assessing 2 year EQ-5D scores, those in Q2 (0.8 ± 0.1) scored significantly better than those in Q4 (0.7 ± 0.1), whereas those in Q1 (0.8 ± 0.1) scored significantly better than those in Q3 (0.7 ± 0.1) and Q4 (all $p < 0.016$) (Table 4). Changes in NRS, EQ-5D and mJOA scores by Disability Quartile are presented in Figs. 1, 2 and 3.

2-Year deformity of the cohort and disability quartiles

At 2 year follow-up, mean cSVA of the cohort was 34.4 ± 15.6 mm, mean TS-CL was 29.4 ± 13.0°, and mean C2 Slope was 26.8 ± 13.7°. With respect to Ames modifiers, 65.5% of the cohort had a cSVA modifier of 0, 11.2% of the cohort had a TS-CL modifier of 0, and 17.9% of the cohort had a horizontal gaze modifier of 0. At 2 year follow-up, there were no significant differences in radiographic CD between disability quartiles (Table 5).

Multivariable outcomes analysis of disability quartiles

Improvement in NRS Neck scores were significantly different between disability groups ($p = 0.007$). ANCOVA found that patients in Q2 demonstrated the greatest improvement in NRS Neck at 2Y (−3.9), which was greater than those in Q3 (−1.6, $p = 0.032$) and Q4 (−1.4, $p = 0.015$), yet similar to those in Q1 (−3.4). Stepwise logistic regression also indicated that the odds of reaching MCID in NDI scores were significantly different across disability groups ($p = 0.023$). Compared to those in Q2, odds of reaching MCID in NDI scores were significantly lower for those in Q1 (OR: 0.276, 95% CI 0.091–0.843, $p = 0.024$), Q3 (OR: 0.168, 95% CI 0.045–0.624, $p = 0.008$), and Q4 (OR: 0.143, 95% CI

Table 4 2-Year HRQLs and Complications by Disability Quartile

2-year HRQLs	Q1	Q2	Q3	Q4	*p* values
NDI	18.0 ± 14.9	27.6 ± 14.7	41.2 ± 16.4	50.5 ± 21.6	< .001
mJOA	15.3 ± 2.2	15.2 ± 3.1	14.1 ± 3.2	12.9 ± 3.5	.009
NRS neck	2.3 ± 2.1	2.8 ± 2.4	4.8 ± 2.7	5.7 ± 3.1	< .001
NRS back	3.5 ± 3.0	2.9 ± 2.2	5.0 ± 3.1	6.6 ± 2.6	< .001
EQ-5D-3L	0.8 ± 0.1	0.8 ± 0.1	0.7 ± 0.1	0.7 ± 0.1	< .001
Complications by 2 Years					
Dysphagia, %	9.1	6.0	12.7	10.4	0.273
Neurologic, %	13.8	8.0	13.3	12.9	0.320
Symptomatic DJK, %	5.4	8.0	8.5	10.1	0.210
DJF, %	4.7	2.5	4.4	5	0.086
Reoperation, %	10.3	4.0	6.9	5.2	0.305

2-Year HRQLs by Disability Quartile; *Q1* Quartile 1, *Q2* Quartile 2, *Q3* Quartile 3, *Q4* Quartile 4

DJF Distal Junctional Failure, *DJK* Distal Junctional Kyphosis, *NDI* Neck Disability Index, *mJOA* modified Japanese Orthopaedic Association scale, *NRS* Numeric Rating Score, *EQ-5D-3L* EQ-5D Three-Levels

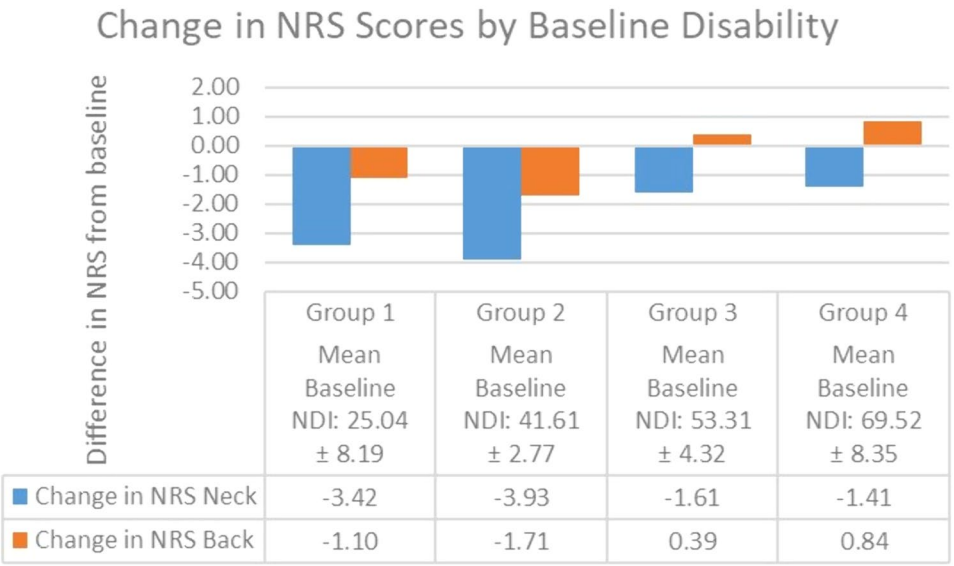

Fig. 1 Change in NRS scores by Disability Quartile

0.035–0.573, $p = 0.006$). Improvement in NRS Back scores were also significantly different between disability groups ($p = 0.007$). Patients in Q2 demonstrated the greatest improvement in NRS Back scores at 2Y (−1.7), which was significantly greater than those in Q4 (+0.8, $p = 0.010$), yet similar to those in Q1 (−1.1) and Q3 (+0.4). Furthermore, patients in Q2 demonstrated the greatest improvement in EQ-5D at 2Y (+0.082), compared to Q1 (+0.073), Q3 (+0.022), and Q4 (+0.014) {$p = 0.034$}. Finally, patients in Q2 demonstrated the greatest improvement in mJOA score from baseline (+1.5), compared to those in Q1 (+1.4), Q3 (+1.1), and Q4 (−0.7) {$p = 0.042$}. There were no differences in odds of meeting MCID in NRS Back, mJOA, or EQ-5D scores between disability groups.

Discussion

The health impact of CD is substantial, with affected patients scoring worse in HRQL metrics than patients suffering from other chronic disease states such as ischemic heart disease [7]. With the increasing frequency of operative interventions done for individuals affected by CD, patient selection and outcome prognostication becomes of increasing importance. There is literature available to aid with decision-making regarding surgical strategies for CD patients on case-by-case bases [8, 19, 20]. Understanding the associations between baseline deformity and post-operative changes in HRQL outcomes

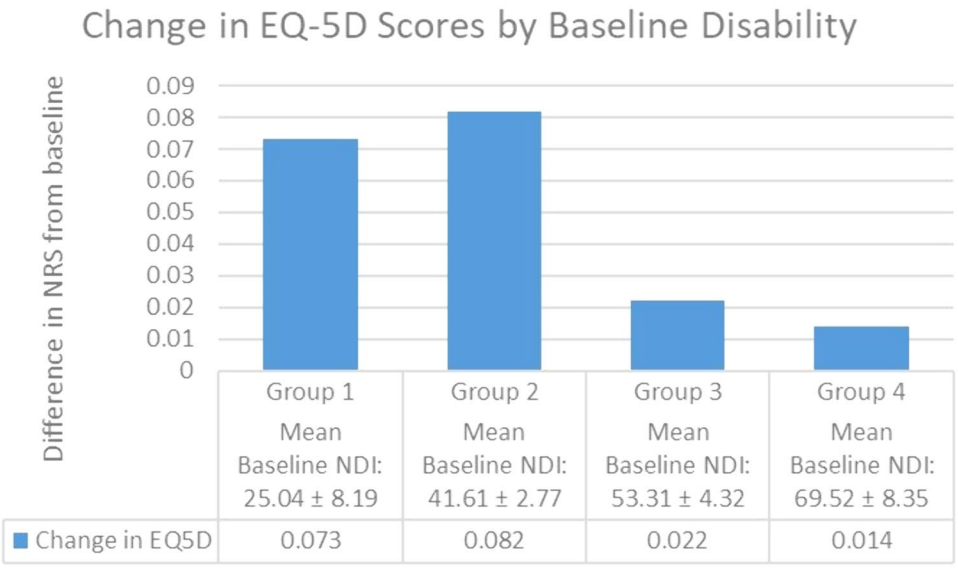

Fig. 2 Change in EQ-5D scores by Disability Quartile

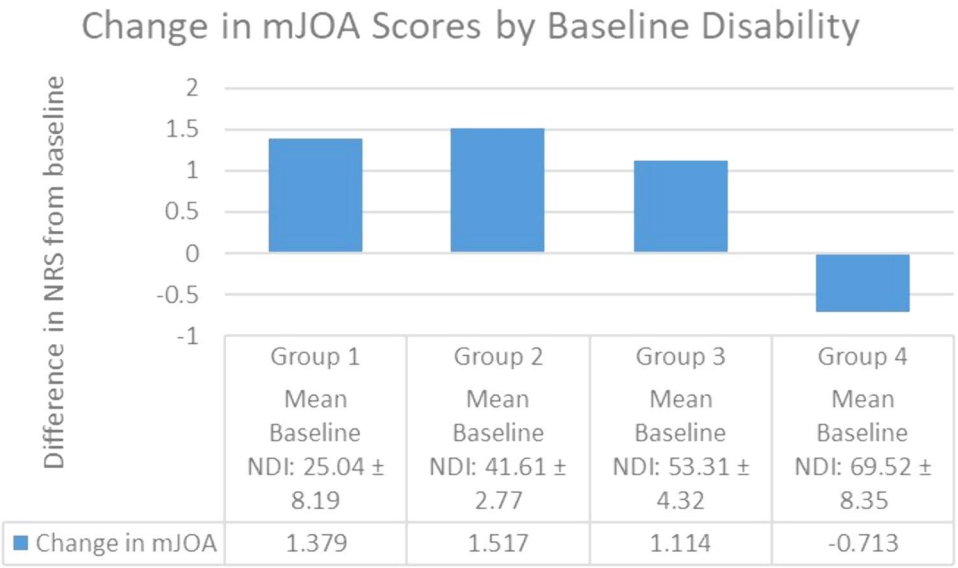

Fig. 3 Change in mJOA scores by Disability Quartile

will further strengthen such patient selection and decision-making processes. In this context, we sought to identify potential thresholds of baseline pre-operative radiographic deformity of the cervical spine and how these influenced the improvements, or lack of, in a variety of patient-reported outcome measures.

Previous studies have examined associations between pre-operative radiographic CD severity and post-operative functional outcomes. Wang et al. analyzed a cohort of 102 cervical myelopathy patients and found that patients with lower pre-operative cervical sagittal vertical axis to T1 slope ratio (CSVA/T1S) achieved significantly higher NDI scores following cervical laminoplasty [21]. This study grouped patients into two groups (low or high CSVA/T1S) based on the median value for the entire cohort. Xu et al. studied a cohort of 181 patients undergoing cervical laminoplasty for posterior longitudinal ligament ossification-related spinal cord compression and reported that patients with higher centre of gravity of head-C7 sagittal vertical axis values (CGH-C7 SVA > 38 mm) were more likely to develop post-operative cervical lordosis loss and suboptimal neurologic improvements (JOA scores) [22]. This study grouped participants into two groups based off a CGH-C7 SVA cutoff value of 38 mm which was chosen due to its sensitivity and specificity in predicting poor neurologic improvements in the study cohort.

In this study, we stratified patients into four quartiles depending on the severity of their functional disability, denoted by their baseline NDI scores. At 2 years post-operatively, patients in Q1 and Q2 exhibited similar

Table 5 2-Year Deformity metrics by Disability Quartile

2-Year deformity	Q1	Q2	Q3	Q4	*p* value
cSVA (mm)	33.5 ± 18.0	34.8 ± 11.5	33.5 ± 15.8	35.9 ± 16.5	> .05
TS-CL (°)	27.4 ± 12.5	28.5 ± 9.6	28.3 ± 14.7	32.6 ± 13.9	> .05
C2 Slope (°)	24.5 ± 13.4	26.8 ± 9.8	25.5 ± 15.3	30.0 ± 15.1	> .05
SVA (mm)	19.0 ± 48.4	21.2 ± 52.1	16.4 ± 79.4	33.5 ± 68.4	> .05
PI-LL (°)	1.2 ± 14.1	5.3 ± 17.2	2.7 ± 17.0	−3 ± 18.5	> .05
PT (°)	19.3 ± 11.3	21.8 ± 11.6	21.1 ± 10.0	16.7 ± 12.0	> .05
Ames modifiers					
cSVA modifier	Q1	Q2	Q3	Q4	*p* value
0	65.5%	72.0%	65.5%	60.6%	> .05
+	34.5%	28.0%	34.5%	39.4%	> .05
+ +	0.0%	0.0%	0.0%	0.0%	> .05
TS-CL modifier	Q1	Q2	Q3	Q4	*p* value
0	10.3%	8.0%	20.7%	6.1%	> .05
+	20.7%	4.0%	17.2%	12.1%	> .05
+ +	69.0%	88.0%	62.1%	81.8%	> .05
Horizontal modifier	Q1	Q2	Q3	Q4	*p* value
0	20.7%	24.0%	7.7%	18.8%	> .05
+	51.7%	48.0%	61.5%	43.8%	> .05
+ +	27.6%	28.0%	30.8%	37.5%	> .05
mJOA modifier	Q1	Q2	Q3	Q4	*p* value
None	27.6%	41.7%	15.4%	9.1%	.020
Mild	31.0%	20.8%	38.5%	24.2%	> .05
Moderate	31.0%	16.7%	19.2%	24.2%	> .05
High	10.3%	20.8%	26.9%	42.4%	.033

2Y Deformity by Disability Quartile; *Q1* Quartile 1, *Q2* Quartile 2, *Q3* Quartile 3, *Q4* Quartile 4

cSVA C2-C7 Sagittal Vertical Axis, *TS-CL* T1 Slope Minus Cervical Lordosis, *mJOA score* modified Japanese Orthopaedic Association score

improvements in NRS Neck and NRS Back scores. However, Q2 patients exhibited greater improvements than the entire cohort with regards to EQ-5D and mJOA scores. Furthermore, Q2 patients had the most significant odds of reaching MCID in NDI scores when compared to all other disability quartiles. Expectedly, less-severe baseline functional disability (as seen in Q1 and Q2 patients) was associated with greater improvement in HRQL metrics post-operatively. However, it was particularly notable that the Q2 patients in our study exhibited the most consistently significant improvements. The baseline mean NDI score of 42 (range 38 to 46) in these patients may represent an optimum range at which patients undergoing CD surgery may experience the maximum possible functional disability improvements. The reasons for this are unclear but could indicate a disability threshold beyond which surgical intervention for CD may begin yielding diminishing returns. We believe the findings from this study may find utilization during the patient selection and consenting process, where they may potentially contribute toward prognosticating the expected functional disability improvements after surgical intervention, based on baseline disability severity. Factors that have been reported to contribute toward the most significant improvements in HRQL metrics include adequate radiographic deformity correction, minimal peri-operative complications, minimal comorbidity burden and absence of mental health disease at baseline [23–25].

We appreciate limitations of this study, including the relatively small sample size, given the multicenter nature of the study; and also the inclusion of a myriad of multiple HRQL scoring systems. There remains a lack of a CD--specific outcome scoring system, and hence multiple previous studies have also relied on a variety of scoring systems to assess post-operative outcomes [23, 24, 26]. Furthermore, we did not include a cost-effectiveness analysis due to difficulty acquiring the necessary data from the multiple institutions involved. Such an analysis may have contributed to the study due to the high costs associated with cervical deformity procedures. In addition, we did not include analyses of psychologic comorbidity treatments, and acknowledge that variations in treatment of these conditions may have influenced patient outcomes. We also have not included an analysis of post-operative rehabilitation regimens and adjuvant treatments, which are expected to

also make potentially significant contributions to changes in functional disability scores.

Conclusion

Patients with mean baseline NDI of 42 consistently demonstrated the greatest improvement in HRQLs, whereas those in the highest Disability Quartile, with mean baseline NDI of 70, saw the least improvement. Thus, baseline NDI between 39 and 44 may represent a disability "sweet spot," within which operative intervention may maximize patient-reported outcomes. Furthermore, delaying intervention until patients are severely disabled, beyond an NDI of 61, may limit the benefits of surgical correction in cervical deformity patients.

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Declarations

Conflict of interest None to disclose.

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