

Supplementary Table 2. Summary of studies examining the association of cervical parameters with patient-reported outcomes in adult cervical deformity

Study	Study design	Country/organization	Study population	No.	Intervention	PRO instruments	Timing of PRO collection	Main findings
Johnson ²² (2019)	Retrospective analysis of a prospective registry of a single institution	USA	Patients presenting with a chief complaint of neck pain and diagnosed with cervical deformity (ACD) (defined as cSVA > 40 mm)	36	No surgical intervention - Questionnaires were completed before each ambulatory clinic visit for neck pain	NDI, EQ-5D, VAS neck pain, VAS arm pain, PROMIS physical function, PROMIS pain intensity, and PROMIS IS pain interference, mFI, CCI	Baseline	- In patients with cervical deformity, less subaxial cervical lordosis (CL) had low but significant correlations with PROMIS pain intensity (CL r = -0.347, p = 0.022) and EQ-5D (CL r = 0.344, p = 0.024) but not NDI. - C1-2 lordosis did not correlate significantly with any PROMIS domain or leg-acy metric, nor did PROMIS physical function or PROMIS pain interference correlate with any alignment parameter.
Pierce ⁴ (2019)	Retrospective analysis of single center database	USA	Patients with ACD defined as (C2-7 Cobb > 10° or cSVA > 4 cm or TS-CL > 15°) - Based on cSVA Ames-ISSG modifier 83.2% had low and 16.8% had moderate ACD. - Based on TS-CL: Ames-ISSG modifier 18.8% had low, 22.1% had moderate, and 59.1% had severe ACD.	208	79.3% posterior approach; 5.7% anterior surgery, and 14.9% combined approach	PROMIS scores for pain interference, PI, and PF	Baseline	- PROMIS domain scores for Pain intensity did not differ between cSVA and TS-CL modifier severity groups. - Moderate cSVA patients and Moderate/Severe TS-CL modifier groups both trended toward lower PF scores and higher pain interference scores, though this was not statistically significant (p > 0.05).
Bakou-ny ²⁵ (2018)	Cross-sectional observational study	Lebanon	Patient's age ≥ 18 years with absence of cervical or back-related complaints - 96.5% Subjects had at least one: Ames-ISSG modifier at grade 1 or 2	141	No intervention	SF-36 HRQoL questionnaire	Baseline	All SF-36 components were similar (p > 0.05) between grades for both the TS-CL and CBVA modifiers.
Ailon ¹⁴ (2017)	Retrospective analysis of a multicenter CD database	International Spine Study Group (ISSG)	Surgically treated ACD patients eligible for 1-yr follow-up - 56.4% had cervical sagittal imbalance; 54.5% cervical kyphosis; 7.3% proximal junctional kyphosis, 9.1% coronal deformity	55	14.5 % Anterior approach; 47.3% posterior-only; 38.2% Combined anterior and posterior; 18.2% PSO; 5.5% vertebral column resection	EQ-5D, NDI, and neck pain NRS, mJOA	Change from baseline to 1-yr follow-up after surgery	- Improvement in global health status as measured by mean EQ-5D (0.51 ± 0.2 to 0.66 ± 0.2, p < 0.001); 56.6% of patients improved by at least 1 MCID for EQ-5D - Reduction in neck pain and neck related disability; corresponded to an increase greater than or equal to the MCID for neck pain NRS (1.3) 25 in 61.8% of patients. A reduction of NDI by at least 1 MCID (19%) was achieved in 55.6% of patients. - Minimal change in myelopathy from a mean baseline mJOA of 13.3 ± 2.6 to 13.5 ± 3.0 (p = 0.675)

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Hyun ²⁸ (2018)	Retrospective cohort study of a single institution experience	South Korea	Patients with a minimum 5-yr follow-up having 3- or more level posterior cervical fusion for ACD	30	Posterior cervical correction	NDI, VAS	Postoperative	<ul style="list-style-type: none"> - Regression models predicted a threshold C2-7 SVA value of 40.8 mm and 70.6 mm correlated with moderate and severe disability based on the NDI score, respectively. - Regression analyses revealed that a C2-7 SVA value of 40 mm and 70 mm corresponded to a TS-CL value of 20° and 25°, respectively. - No other significant correlations were identified between the radiographic parameters and VAS scores for axial neck pain
Poorman ¹⁵ (2017)	Retrospective analysis of a prospective, multicenter ACD database	International Spine Study Group (ISSG)	<ul style="list-style-type: none"> - Patient diagnosed with ACD and underwent surgical correction of the deformity - Cohort divided between those with depression vs. no depression 	66	<ul style="list-style-type: none"> - Depressed group: Anterior approach (n = 8;24.2%), posterior approach (n = 17;51.5%), combined approach (n = 8;24.2%) - Nondepressed group: anterior approach (n = 2;6.1%); posterior approach (n = 17;51.5%); combined approach (n = 14;42.4%) 	NRS, EQ-5D, Neck NDI, mJOA	3 mo, 6 mo, and 1 yr postoperatively	<ul style="list-style-type: none"> - At 3 months, EQ-5D scores remained lower in the depressed group, and NDI scores were similar. Neck pain improved in the depressed group and mJOA scores remained similar. - At 6 months and 1 year, all HRQoL scores were similar between depressed and nondepressed groups
Oe ²⁶ (2017)	Retrospective cohort study of a single institution experience	Japan	Patients diagnosed with ACD (defined as cSVA > 40 mm)	118	No intervention	EQ-5D	Baseline	<ul style="list-style-type: none"> - In males EQ-5D in showed significantly greater deterioration the ACD group than in the non-ACD group - In females, no difference in EQ-5D between ACD and non-ACD groups. - Correlation between EQ-5D and PT, C7 SVA and C2 SVA in females - No correlation of EQ-5D and cervical parameters in males.

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Passias ³² (2018)	Retrospective analysis of a multicenter ACD database	International Spine Study Group (ISSG)	Patients diagnosed with ACD as defined by the presence of at least 1 of the following on baseline imaging: cervical kyphosis (C2-7 Cobb angle > 10), cervical scoliosis (C2-7 coronal Cobb angle < 10), cSVA > 4 cm, or CBVA > 25	73	Posterior approach EQ-5D; NDI; mJOA	EQ-5D; NDI; mJOA	Baseline and 1-yr postoperative visits	<ul style="list-style-type: none"> - Within primary drivers (PD) patients operated at cervical driver level showed significant 1-year HRQL improvements (Table 4) and trended toward improvement in Ames TS-CL modifier at a greater rate than did patients with PDs not included in surgery.
Passias ¹⁶ (2018)	Retrospective analysis of a multicenter ACD database	International Spine Study Group (ISSG)	Patients diagnosed with ACD as defined by the presence of at least 1 of the following on	70	45.7% Posterior approach, 15.7% anterior approach, and 38.6% combined approach	EQ-5D; NDI; mJOA	Baseline and 1-yr postoperative visits	<ul style="list-style-type: none"> - Global parameters of C2-S1 SVA and C7-S1 SVA showed significant correlations with overall 1-year mJOA, EQ-5D, and NDI.
Horn ¹⁹ (2020)	Retrospective analysis of a multicenter ACD database	International Spine Study Group (ISSG)	Patients diagnosed with ACD as defined by the presence of at least 1 of the following on baseline imaging: cervical kyphosis (C2-7 Cobb angle > 10), cervical scoliosis (C2-7 coronal Cobb angle < 10), C2-7 cervical sagittal vertical axis (cSVA) > 4 cm, or chin-brow vertical angle (CBVA) > 25, and mJOA scores 17 or lesser baseline imaging: cervical kyphosis (C2-7 Cobb angle > 10), cervical scoliosis (C2-7 coronal Cobb angle < 10), cSVA > 4 cm, or CBVA > 25	63	49.2% Posterior approach, 17.5% anterior approach, and 33.3% combined approach	mJOA; EQ-5; NDI	1-yr postoperative improvement	<ul style="list-style-type: none"> - Improvements in functional outcomes, as defined by mJOA score, were correlated with changes in neck-based disability and general health state, defined by NDI and EQ-5D respectively. - While correlations exist between outcome measures, when modeling these outcomes while controlling for confounders including cSVA change, surgical invasiveness, age and CCI, these HRQoLs were not strongly correlated.

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Grosso ²³ (2013)	Retrospective cohort study of a single institution experience	USA	Patients with myelopathic symptoms who underwent cervical deformity correction surgery	36	34 % posterior approach, and 55 % anterior approach combined approach	mJOA	Baseline and postoperative	<ul style="list-style-type: none"> - A significant relationship was observed between a greater degree of focal kyphosis correction and improved neurological outcomes (mJOA). - Patients with severe neurological symptoms (mJOA score <12) a trend toward improved outcomes with greater global kyphosis correction. - Patients with an mJOA score less than 16 who attained lordosis postoperatively had a significantly greater improvement in total mJOA score than patients who maintained a kyphotic position.
Virk ⁸ (2020)	Retrospective analysis of a prospective, multicenter ACD database	International Spine Study Group (ISSG)	Patients diagnosed with ACD as defined by the presence of at least 1 of the following on baseline imaging: cervical kyphosis (C2-7 Cobb angle > 10), cervical scoliosis (C2-7 coronal Cobb angle < 10), cSVA > 4 cm, or CBVA > 25	153	Details of surgical approaches not provided	NDI, mJOA, NRS-neck - Postoperative outcomes were defined as "good" if a patient had ≥ 2 of the 3 following criteria (1) NDI < 20 or meeting MCID, (2) mild myelopathy (mJOA ≥ 14), and (3) NRS-Neck ≤ 5 or improved by ≥ 2 points from baseline	Baseline and 1-yr postoperative	<ul style="list-style-type: none"> - Within the FD cohort, maximal focal kyphosis (i.e., kyphosis at one level) was better corrected in patients with a "good" outcome - In the FN cohort, patients with "good" outcomes presented preoperatively with worse horizontal gaze (McGregor slope 21° vs. 6°, p = 0.061) and cSVA (72 mm vs. 60 mm, p = 0.030) - In the CT cohort, patients with "good" outcomes had superior global alignment both pre- (SVA: -17 mm vs. 108 mm, p < 0.001) and postoperatively (50 mm vs. 145 mm, p = 0.001) - CT patients with "good" outcomes also had better postop cervical alignment (cSVA 35 mm vs. 49 mm, p = 0.030), and less kyphotic segments during extension - In the FD cohort, there were no differences between "good" and "poor" outcomes patients in preoperative alignment

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Study	Study design	Country/organization	Study population	No.	Intervention	PRO instruments	Timing of PRO collection	Main findings
Smith ³ (2017)	Retrospective analysis of a multicenter ACD data-base	International Spine Study Group (ISSG)	ACSD patients presenting for surgical treatment	115	No intervention	EQ-5D	Baseline	<ul style="list-style-type: none"> - Mean ACSD EQ-5D index was 0.511 (standard definition = 0.224), which is 34% below the bottom 25th percentile (0.780) for similar age- and gender-matched US normative populations - Mean ACSD EQ-5D index values were worse than the bottom 25th percentile for several other disease states, including chronic ischemic heart disease (0.708), malignant breast cancer (0.708), and malignant prostate cancer (0.708) - EQ-5D scores did not significantly differ based on cervical deformity type (p = 0.66)
Zhong ²⁹ (2018)	Prospective cohort study in a single institution	China	Chronic AAD-related kyphosis	21	C1-2 reduction and correction surgery	NDI, SF-12 PCS, and JOA	Baseline and postoperative	<ul style="list-style-type: none"> - An improvement in the JOA score was associated with changes in the C1-2 Cobb angle, C0-2 Cobb angle, and C2-7 Cobb angle - Improvement in NDI was associated with the changes in the C1-2 Cobb angle, C0-2 Cobb angle, C2-7 Cobb angle, C2-7 SVA, and cranial tilt - Amelioration of SF-12 PCS was relevant to the changes in the C1-2 Cobb angle, C0-2 Cobb angle, and C2-7 Cobb angle
Horn ¹⁹ (2019)	Retrospective analysis of a multicenter ACD data-base	International Spine Study Group (ISSG)		89	Posterior approach (49.4%); anterior approach (16.9%); combined (33.7%)	NDI, EQ-5D, mJOA	Baseline and postoperative	<ul style="list-style-type: none"> - 80% and 60% of patients did not reach MCID for EQ-5D and NDI, respectively, and 24% of patients had severe symptoms (mJOA score 0-11)
Bao ²⁴ (2017)	Retrospective cohort study of a single institution experience	USA	Patient with ACD, no history of cervical surgery, and a well-compensated thoracolumbar profile (defined as a T1-pelvic angle < 15).	171	No intervention	NDI, VAS arm, VAS neck	Baseline	<ul style="list-style-type: none"> - C2-7 SVA and SLS as independent risk factors for low health-related quality of life

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Segreto ²⁰ (2019)	Retrospective analysis of a prospective multicenter ACD database	International Spine Study Group (ISSG)	Operative ACD patients (> 18 years old), undergoing a primary or revision procedure, with complete preoperative to 1-yr postoperative HRQoL data	83	Surgical intervention (primary and revision surgery)	NRS-neck, NRS-back, NDI, mJOA, and EQ-5D	Baseline and 1-yr postoperative	Primary patients (compared to revision surgery group) exhibited significantly lower normalized NRS-neck pain scores by 6 mo (0.48 vs. 0.68; p = 0.037), as well as lower normalized NRS-neck pain (0.51 vs 0.83, p = 0.017) and improved normalized mJOA (1.11 vs. 0.97, p = 0.007) by 1-yr follow-up
Protosaltis ³⁰ (2018) ISSG	Retrospective analysis of a prospective multicenter ACD database	International Spine Study Group (ISSG)	ACD surgical patients with apex of deformity in the cervical or cervicothoracic regions	104	Surgical correction	EQ5D, mJOA, NRS-neck pain, NDI	Baseline and 1-yr postoperative	Worse 1-yr postoperative C2 slope correlated with worse health outcomes
Lee ²⁷ (2014)	Retrospective case-control	Republic of Korea	Patients diagnosed with ankylosing spondylitis (AS)	102 AS patients and 50 controls	No intervention	VAS for neck pain, NDI, NPAD, scale and bath ankylosing spondylitis disease activity index were administered to evaluate QoL	Baseline	Correlation analysis revealed significant relationships between radiographic parameters and QoL. In particular, C2-7 SVA was found to be a significant predictor of QoL in AS patient

PRO, pedicle subtraction osteotomy; ACD, adult cervical deformity; cSVA, C2-7 sagittal vertical axis; NDI, Neck Disability Index; EQ-5D, EuroQoL 5-Dimension; VAS, visual analogue scale; PROMIS, Patient-Reported Outcomes Measurement Information System; mFI₁, CCI, Charlson Comorbidity Index ; TS-CL, T1 slope minus cervical lordosis; PI, pelvic incidence; PE, physical function; SF-36, 36-item Short Form Health Survey; HRQoL, health-related quality of life; CBVA, correlation of chin-brow vertical angle; NRS, Numerical Rating Scale; mJOA, modified Japanese Orthopedic Association; MCID, minimal clinically important difference; FD, focal deformity; FN, flat neck; ACSD, adult cervical spine deformity; AAD, atlantoaxial anterior dislocation; SF-12 PCS, 12-item Short Form health survey; physical composite score; SLS, slope of line of sight; NPAD, neck pain and disability.