

Clinical Study

Patient profiling can identify patients with adult spinal deformity (ASD) at risk for conversion from nonoperative to surgical treatment: initial steps to reduce ineffective ASD management

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Abstract

BACKGROUND CONTEXT: Non-operative management is a common initial treatment for patients with adult spinal deformity (ASD) despite reported superiority of surgery with regard to outcomes. Ineffective medical care is a large source of resource drain on the health system. Characterization of patients with ASD likely to elect for operative treatment from non-operative management may allow for more efficient patient counseling and cost savings.

PURPOSE: This study aimed to identify deformity and disability characteristics of patients with ASD who ultimately convert to operative treatment compared with those who remain non-operative and those who initially choose surgery.

STUDY DESIGN/SETTING: A retrospective review was carried out.

PATIENT SAMPLE: A total of 510 patients with ASD (189 non-operative, 321 operative) with minimum 2-year follow-up comprised the patient sample.

OUTCOME MEASURES: Oswestry Disability Index (ODI), Short-Form 36 Health Assessment (SF-36), Scoliosis Research Society questionnaire (SRS-22r), and spinopelvic radiographic alignment were the outcome measures.

METHODS: Demographic, radiographic, and patient-reported outcome measures (PROMs) from a cohort of patients with ASD prospectively enrolled into a multicenter database were evaluated. Patients were divided into three treatment cohorts: Non-operative (NON=initial non-operative treatment and remained non-operative), Operative (OP=initial operative treatment), and Crossover (CROSS=initial non-operative treatment with subsequent conversion to operative treatment). NON and OP groups were propensity score-matched (PSM) to CROSS for baseline demographics (age, body mass index, Charlson Comorbidity Index). Time to crossover was divided into early (<1 year) and late (>1 year). Outcome measures were compared across and within treatment groups at four time points (baseline, 6 weeks, 1 year, and 2 years).

RESULTS: Following PSM, 118 patients were included (NON=39, OP=38, CROSS=41). Crossover rate was 21.7% (41/189). Mean time to crossover was 394 days. All groups had similar baseline sagittal alignment, but CROSS had larger pelvic incidence and lumbar lordosis (PI-LL) mismatch than NON (11.9° vs. 3.1°, $p=.032$). CROSS and OP had similar baseline PROM scores; however, CROSS had worse baseline ODI, PCS, SRS-22r ($p<.05$). At time of crossover, CROSS had worse ODI (35.7 vs. 27.8) and SRS Satisfaction (2.6 vs. 3.3) compared with NON ($p<.05$). Alignment remained similar for CROSS from baseline to conversion; however, PROMs (ODI, PCS, SRS Activity/Pain/Total) worsened ($p<.05$). Early and late crossover evaluation demonstrated CROSS-early ($n=25$) had worsening ODI, SRS Activity/Pain at time of crossover ($p<.05$). From time of crossover to 2-year follow-up, CROSS-early had less SRS Appearance/Mental improvement compared with OP. Both CROSS-early/late had worse baseline, but greater improvements, in ODI, PCS, SRS Pain/Total compared with NON ($p<.05$). Baseline alignment and disability parameters increased crossover odds—Non with Schwab T/L/D curves and $ODI\geq 40$ (odds ratio [OR]: 3.05, $p=.031$), and Non with high PI-LL modifier grades (“+”/“++”) and $ODI\geq 40$ (OR: 5.57, $p=.007$) were at increased crossover risk.

CONCLUSIONS: High baseline and increasing disability over time drives conversion from non-operative to operative ASD care. CROSS patients had similar spinal deformity but worse PROMs than NON. CROSS achieved similar 2-year outcome scores as OP. Profiling at first visit for patients at risk of crossover may optimize physician counseling and cost savings. © 2017 Published by Elsevier Inc.

Keywords: Adult spinal deformity; Crossover; Disability; Non-operative treatment; Operative treatment; Patient profiling

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EVIDENCE & METHODS

Context

Identifying patient-specific characteristics that might correlate with differences in response to treatments is a key to streamlining care. The authors aimed to identify such features for ASD patients.

Contribution

They found that high baseline disability and disability that increased with time (given similar curve characteristics) were identifiable factors associated with crossover from nonop treatment to operative treatment in these patients at two years.

Implications

The information might prove useful for individualized informed consent and decision-making. Streamlining care (avoiding likely ineffective interventions, saving time, saving money, etc.) when the evidence is compelling makes sense. It is of note that peer review raised some concerns over the statistical methods used but the study serves as a solid starting point and the findings “make sense.”

Introduction

Adult spinal deformity (ASD) presents a significant physiological burden with increasing socioeconomic relevance, as estimates place the condition's incidence exceeding 60% [1]. High correlations of unfavorable sagittal spinopelvic alignment with patient-reported outcome measures (PROMs) have been demonstrated, highlighting ASD's critical role in driving disability [1–3]. Methods for achieving timely and effective ASD management have therefore risen to the forefront of discourse postulating optimal treatment.

Evolutions in clinical decision making are marked by increasingly evidence-based approaches. This is particularly salient for comparing surgical versus non-operative treatments, a burgeoning topic in the context of spinal deformity wherein substantial morbidity accrued during surgical correction may delay or offset improvements [4–6]. It is widely accepted that first-line treatment in patients with ASD without neurologic deficit or instability is non-operative care, typically involving bracing, physical therapy, steroid injections, and NSAIDs [7]. But ASD's natural progression may negate the benefits of conservative care, thus driving patients to transition to operative management.

Comparative studies have highlighted significant 2-year clinical improvements in operative patients with ASD, whereas reports on non-operative deformity management show prolonged maintenance, at best, of pain and disability [8–10]. In defining those patients with ASD that do improve through conservative care, Slobodyanyuk et al. reported a link between heightened baseline disability and achievement of 1-year

minimum clinical important difference (MCID) [11]. This wider margin for improvement also extends to patients opting for immediate surgical correction: Fu et al. found that poorer baseline PROM and scoliosis magnitude determined operative ASD treatment success [12]. Matching ideal ASD realignment in sagittal and coronal planes also displays a demonstrated impact on outcome scores [8,10].

Little is known of patient-specific factors for those individuals who abandon non-operative care in favor of surgery. In one of the few studies evaluating conversion patients, Weinstein et al. reported an incidental 17% crossover rate, though in lumbar spondylolisthesis [13]. Although the clinical impact of delaying surgery has yet to be evaluated in ASD, such an analysis is valuable from a patient-outcome and resource utilization vantage, as extended non-operative management for degenerative spine conditions has been linked with prolonged pain and discomfort [14]. Moreover, data mitigating the cost-effectiveness of non-operative ASD treatment on outcomes underscore the requirement for effective patient care, which may be facilitated with proper patient profiling at first visit [15].

The main study objective was thus to define the spinal deformity and disability profile of ASD conversion patients compared with those who selected and remained with non-operative or operative treatment, derived from a prospective, multicenter database. Two-year outcomes and risk factors increasing the likelihood of treatment transition were also evaluated. Effective characterization of this ASD crossover cohort may permit more efficient patient counseling and cost savings.

Methods

Data source

This study was a multicenter retrospective review of consecutive patients with ASD enrolled from 2008 to 2014 from 11 participating centers in the United States. Institutional Review Board approval was obtained at each participating site before patient enrollment. Database inclusion criteria were patients ≥ 18 years seeking either operative or non-operative treatment for ASD, defined as meeting the following criteria at baseline presentation: degenerative or idiopathic scoliosis $\geq 20^\circ$ (measured by major coronal Cobb angle), sagittal vertical axis (SVA) ≥ 5 cm, pelvic tilt (PT) $\geq 25^\circ$, and thoracic kyphosis (TK) $> 60^\circ$. The authors received a financial grant that was unrelated to the production of this work.

Patient treatment groups

This study included all patients with ASD who underwent either surgical or non-operative treatment following study enrollment with complete 2-year follow-up. The decision to pursue each treatment modality was based on discussion between the patient and their enrolling surgeon. Identified patients were divided into three cohorts based on the selected treatment type at enrollment and continuation through follow-up: (1) NON=initial non-operative treatment and

remained non-operative; (2) OP=operative treatment immediately upon enrollment into database; (3) CROSS=initial non-operative treatment with subsequent conversion to operative treatment, after at least 6 weeks of non-operative care. Patient data specific to the CROSS group were available for the period from non-operative enrollment to conversion, and subsequent to conversion to operative management. These patients were prospectively enrolled into the operative study arm and followed prospectively through complete operative follow-up. Time to crossover was also evaluated and dichotomized into CROSS-Early (<1-year) and CROSS-Late (\geq 1-year) groups.

Data collection

Included patients had 36-inch full-length films available for analysis for all visits. Radiographic measurements were performed using validated software (SpineView; ENSAM Laboratory of Biomechanics, Paris, France) at a single center [16,17]. Considered sagittal and coronal measurements were PT, pelvic incidence (PI), mismatch between pelvic incidence and lumbar lordosis (PI-LL), SVA, and coronal thoracic (TH), lumbar (LL), and maximal (TL) Cobb angles.

The SRS-Schwab ASD classification was applied to all patients at enrollment [18]. The classification evaluates coronal curve type (T=Thoracic only [lumbar curve $<30^\circ$], L=Lumbar only [thoracic curve $<30^\circ$], D=Double curve [T and L curves $>30^\circ$], N=No major coronal deformity [coronal curves $<30^\circ$]) and sagittal alignment using three modifiers (PT, PI-LL, and SVA), all graded according to increasing deformity (0: normal, +: moderately abnormal, and ++: markedly abnormal).

Patient visits occurred at the following intervals: non-operative/operative enrollment (baseline), 6-weeks', 1-year, and 2-years' follow-up. At each visit, PROM were collected for analysis, including the Oswestry Disability Index (ODI), Short-Form 36 Health Assessment (SF-36) Physical (PCS) and Mental (MCS) Component Scores, Scoliosis Research Society Questionnaire (SRS-22r) Total score with subsections (Activity, Pain, Appearance, Mental, Satisfaction), and Numeric Rating Scale (NRS) for Back and Leg Pain [19–21]. Minimal clinically important difference (MCID) values were used to evaluate threshold changes in patients' outcomes during treatment. The selected MCID values were 12.8 for ODI, 4.9 for SF-36 PCS, 0.587 for SRS Pain, 0.8 for SRS Appearance, 0.375 for SRS Activity, and 0.42 for SRS Mental, based on prior publications [22–27].

Statistical analysis

A “genetic” propensity scoring matching (PSM) technique was initially used with R Foundation for Statistical Computing (Vienna, Austria) programming to match NON and OP patients to the CROSS group, on the basis of age, body mass index (BMI), and Charlson Comorbidity Index (CCI) score [28,29]. Propensity scoring matching is a logistic regression technique permitting group comparisons by removing

significant variations between groups to simulate a randomization process [30]. The “genetic” matching method identifies the sets of matches which minimize the discrepancies between the distribution of potential confounders in the treated and control groups, minimizing loss of cases [28]. Following PSM, analyses on matched cohorts were effectuated with SPSS software (SPSS, Inc. Version 20.0, IBM Corp, Armonk, NY, USA). Frequency distributions were performed for all variables in each patient group. Independent and paired *t* tests for PROM and radiographic alignment compared continuous variable distributions across and within treatment groups, respectively, at all available time points. Pearson χ^2 and binary logistic regression models evaluated predictors for CROSS likelihood. A *p* value $<.05$ was used for statistical significance.

Results

Patient sample

There were 510 patients with ASD (OP=321, NON=189) identified (mean age 55.7 ± 13.3 years; mean BMI 26.6 kg/m^2 ; 84.7% women). The overall crossover rate was 21.7%, and the mean time to crossover was 393.6 days. Baseline group comparison of demographic and clinical variables is provided in Table 1. Following PSM, 118 patients were used for analysis: OP=39, NON=38, CROSS=41.

First-visit deformity and disability comparisons

As a result of the PSM, all treatment groups were similar for age (59.8 ± 11.2), BMI (28.3 kg/m^2), gender (73% women), smoking status (15.7%), and CCI (1.34; $p>.05$ all cases). Groups also displayed comparable rates of baseline depression (NON=52.6%, OP=57.1%, CROSS=47.7%), diabetes (NON=40.0%, OP=62.5%, CROSS=60.0%), neurologic disease (NON=50.0%, OP=66.7%, CROSS=50.0%), and osteoporosis (NON=71.4%, OP=71.4%, CROSS=28.6%). At enrollment, CROSS patients were similar to NON and OP groups in all sagittal and coronal alignment parameters ($p>.05$),

Table 1

ANOVA comparison of baseline demographic and clinical variables between the three patient study groups (OP, NON, and CROSS) before propensity score matching

	OP	NON	CROSS	<i>p</i>
Age	57.4 \pm 15.0	52.7 \pm 16.3	55.2 \pm 14.6	.002*
BMI	27.3 \pm 6.2	25.5 \pm 5.7	27.4 \pm 6.3	.001*
CCI	1.7 \pm 1.7	0.9 \pm 1.1	1.4 \pm 1.6	<.001*
Sex (%F)	81.1	86.4	90.2	.121
Depression (%)	25.7	16.0	22.5	.024*
Diabetes (%)	7.3	4.2	7.5	.294
Neurologic (%)	4.7	1.7	2.5	.149
Osteoporosis (%)	15.0	10.9	5.0	.119
Smoking Hx (%)	9.5	11.4	5.3	.459

ANOVA, analysis of variance; OP, operative; NON, non-operative; CROSS, crossover; BMI, body mass index, CCI, Charlson Comorbidity Index.

* Values in bold indicate statistically significant difference between NON and CROSS groups, $p<.05$.

Table 2

Independent *t* tests for baseline radiographic alignment parameter comparison for the three adult spinal deformity patient groups (OP, NON, and CROSS) following Propensity Score Matching

	OP	NON	CROSS	p
PT	21.8±10.9	19.3±10.0	21.6±11.8	.362
PI	55.1±10.9	52.7±12.0	52.1±12.6	.830
PI-LL	11.9±21.4	3.1±17.4	11.9±18.6	.032*
SVA	52.3±81.5	16.1±54.8	38.3±62.4	.098
TH Cobb	27.9±22.7	7.2±34.4	14.9±33.1	.420
LL Cobb	24.0±14.1	-10.5±27.3	28.8±10.8	.198
TL Cobb	40.1±25.1	40.4±16.5	40.7±26.3	.965

OP, operative; NON, non-operative; CROSS, crossover; LL, lumbar; PI, pelvic incidence; PI-LL, pelvic incidence minus lumbar lordosis; PT, pelvic tilt; SVA, sagittal vertical axis; TH, thoracic; TL, thoracolumbar.

* Value in bold indicates statistically significant difference between NON and CROSS groups, $p < .05$.

except that CROSS displayed greater PI-LL mismatch than NON (11.9° vs. 3.1°, $p = .032$) (Table 2). All groups had comparable SRS-Schwab ASD coronal curve type distributions: NON (N=15.8%, T=5.3%, L=47.4%, D=31.6%), CROSS (N=15.0%, T=5.0%, L=52.5%, D=27.5%), OP (N=17.1%, T=4.9%, L=51.2%, D=26.8%). PI-LL, SVA, and PT SRS-Schwab modifier grade distributions at baseline were also similar for all groups ($p > .05$ all cases).

However, ASD treatment cohorts displayed significantly different baseline disability (Fig. 1). CROSS patients were consistently worse than NON in pain and function, as displayed in increased ODI (39.4 vs. 27.8), SRS-22r Pain (2.4 vs. 3.1), and NRS Back (6.9 vs. 5.0) and Leg (4.6 vs. 3.1)

pain scores ($p < .05$ all cases). PROM for CROSS patients were also significantly worse for overall physical health, gauged by the SF-36 PCS (33.80 vs. 40.32) and SRS-22r Activity (3.07 vs. 3.63), Appearance (2.59 vs. 3.10), and Total (2.88 vs. 3.37) subsections ($p < .05$ all cases). CROSS and OP treatment groups were similar for PROM, with the exception of different baseline SRS-22r Satisfaction.

Time to crossover analysis

CROSS patients were assessed for progression in deformity and disability from enrollment visit to conversion. From non-operative enrollment, $n = 24$ patients (59.5%) converted to operative care within 1-year (CROSS-Early), and $n = 17$ (40.5%) transitioned between 1 and 2 years (CROSS-Late). CROSS-Early and CROSS-Late were similar for sagittal and coronal alignment at baseline enrollment, despite a trend for CROSS-Early patients to display larger SVA (52.0 mm vs. 17.8 mm, $p = .065$), and at time of crossover ($p > .05$ all cases). Moreover, there was no significant progression of deformity noted in either CROSS-Early/Late groups from enrollment to conversion ($p > .05$ all cases).

Among all CROSS patients, significant decreases in PROM were observed in ODI, SF-36 PCS, and SRS-22r Activity, Pain, and Total from non-operative enrollment to operative baseline (Table 3). CROSS patients reached thresholds for MCID deterioration in the following categories: 15% ODI, 40% SF-36 PCS, 7.5% SRS-22r Pain, 82.5% SRS-22r Appearance, 85.0% SRS-22r Activity, 42.5% SRS-22r Mental. PROMs were non-different when comparing between CROSS timing groups at

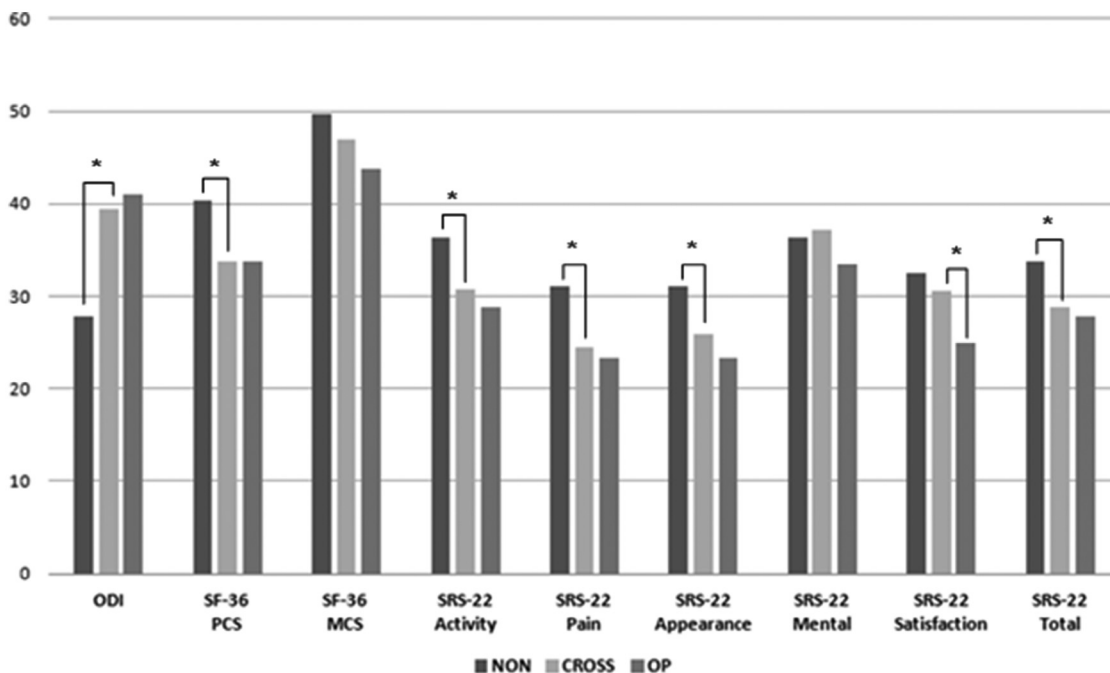


Fig. 1. Comparison of baseline patient-reported outcome measures (PROMs) scores for non-operative (NON), operative (OP), and crossover (CROSS) ASD patient groups. SRS-22r scores have been multiplied by 10. *Denotes statistical significance set to $p < .05$ between indicated patient groups. ODI, Oswestry Disability Index; SF, Short-Form; PCS, Physical Component Summary; MCS, Mental Component Summary; SRS, Scoliosis Research Society.

Table 3

Paired *t* tests for patient-reported outcome measures (PROMs) for crossover (CROSS) timing groups (CROSS-Early [<1 y] and Cross-Late [≥ 1 y])

	CROSS (n=42)		CROSS-early (n=25)		CROSS-late (n=17)	
	Non BL	Op BL	Non BL	Op BL	Non BL	Op BL
ODI	35.7±17.6	40.1±14.3*	36.0±17.6	40.3±13.8*	35.4±18.2	37.9±13.8
Δ	4.4±13.1		5.8±12.8		2.5±13.7	
SF-36 PCS	36.8±8.9	33.3±9.3*	36.1±8.3	33.4±8.5	37.7±9.8	33.2±10.5*
Δ	-3.5±7.3		-2.6±7.1			
SF-36 MCS	45.1±12.6	46.7±11.1	43.9±11.6	45.0±10.5	46.6±14.1	48.8±11.9
Δ	1.6±10.7		1.1±10.2		2.2±11.5	
SRS AC	3.4±0.9	3.0±0.9*	3.3±0.8	2.9±0.9*	3.4±1.1	3.1±0.9
Δ	-0.4±0.8		-0.4±0.7		-0.3±0.9	
SRS P	2.7±0.9	2.4±0.8*	2.6±0.8	2.3±0.8*	2.8±1.1	2.5±0.8
Δ	-0.3±0.7		-0.3±0.7		-0.2±0.8	
SRS AP	2.7±0.8	0.6±0.7	2.8±0.8	2.6±0.7	2.6±0.9	2.5±0.6
Δ	-0.2±0.7		-0.2±0.6		-0.2±0.8	
SRS M	3.6±1.0	3.69±0.9	3.5±1.0	3.7±0.9	3.71±1.16	3.65±0.93
Δ	0.1±0.8		0.2±0.8		-0.06±0.75	
SRS S	2.7±1.1	3.1±1.0*	2.5±1.0	2.9±0.9	2.8±1.1	3.3±1.1
Δ	0.4±1.1		0.3±0.9		0.5±1.2	
SRS T	3.0±0.6	2.8±0.6*	3.0±0.6	2.8±0.6	3.1±0.7	2.9±0.6
Δ	-0.2±0.6		-0.2±0.5		-0.2±0.7	

AC, activity; AP, appearance; M, mental; MCS, Mental Component Summary; ODI, Oswestry Disability Index; P, pain; PCS, Physical Component Summary; S, satisfaction; SF, Short-Form; SRS, Scoliosis Research Society; T, total.

Scores from CROSS patients are reported at non-operative enrollment (Non BL) and at time of treatment conversion (Op BL). Δ refers to the difference in the respective score from enrollment to time of crossover.

* Statistically significant difference within each CROSS group, to $p < .05$.

both baseline enrollment and conversion time. Analysis within conversion timing groups showed significant worsening in ODI (36.0 to 41.7), SRS-22r Activity (3.3–2.9), and Pain (2.6–2.3) among CROSS-Early; CROSS-Late only deteriorated in physical functioning by conversion point (SF-36 PCS: 37.7–33.2).

Additionally, the difference in PROMs from non-operative baseline to the point of conversion for each score was similar between CROSS-Early and CROSS-Late groups. A minimum of 12.5% of patients in both CROSS-Early and CROSS-Late groups met thresholds for MCID deterioration in each PROM category. However, the proportion of those patients who met MCID deterioration was not significantly different between timing groups ($p > .05$ all cases).

Two-year follow-up analysis

Paired analysis for treatment groups demonstrated that all OP and CROSS patients significantly improved in every PROM evaluated from baseline enrollment to 2-year follow-up ($p < .05$ all cases). However, NON did not significantly improve in any measure.

Two-year PROMs were compared between treatment groups (Table 4). NON and CROSS groups had similar PROMs in all categories, except for SRS-22r Appearance and Satisfaction, in which conversion patients had significantly better scores. Given significant differences at baseline between NON and CROSS, CROSS had resulting greater improvements in outcomes at 2 years as well. Based on similar baseline scores between groups, CROSS-Early only had signifi-

cantly reduced improvement at 2 years in the SRS-22r Mental subcomponent compared with OP (0.04 vs. 0.6, $p = .027$).

Patient profiling at first-visit

NON patients at enrollment were analyzed for radiographic and demographic factors that were positively associated with likelihood of treatment conversion to OP. Baseline PROM for physical disability (ODI and SF-36 PCS and sub-scores) were compared between NON and CROSS groups (Fig. 2), and significant scores were dichotomized based on means: ODI ≥ 40 , SF-36 PCS ≥ 35 , RF ≥ 30 , RP ≥ 35 , BP ≥ 35 , VT ≥ 40 .

NON patients were evaluated for clinical and radiographic variables that increased the likelihood of becoming a CROSS case. At the time of non-operative enrollment, NON with Schwab T/L/D curves and ODI ≥ 40 (OR: 3.1, $p = .031$), and NON with high PI-LL modifier grades (“+”/“++”) and ODI ≥ 40 (OR: 5.6, $p = .007$) were at significantly increased crossover risk (Table 5).

Case example

A 54-year-old woman with ASD with no prior spine surgery (Fig. 3) was enrolled into the non-operative arm of the database as a NON patient. According to the crossover profiling results, her non-operative enrollment ODI met the proposed ≥ 40 disability threshold (46), and she displayed markedly abnormal (++) spinopelvic mismatch (PI-LL = 20°) with both coronal thoracic (40°) and thoracolumbar (59°) curves $> 30^\circ$ (Fig. 3, Left). She was followed non-operatively for 383 days

Table 4

Paired *t*-test results for baseline and 2-year follow-up patient-reported outcome measures (PROMs) comparison for crossover (CROSS; CROSS-Early [<1 y] and Cross-Late [≥ 1 y]), non-operative (NON), and operative (OP) patient groups

		NON (n=39)	OP (n=38)	CROSS (n=42)	CROSS-early (n=25)	CROSS-late (n=17)	Significance
ODI	BL	27.7±16.7	41.1±21.1	39.3±15.0	40.3±16.1	37.9±13.8	N vs. C, C-E*
	2 y	27.7±18.0	26.9±22.8	28.8±22.4	30.1±21.2	27.1±24.5	None
	Δ	-0.1±8.5	-14.2±17.7	-10.5±18.5	-10.3±17.5	-10.9±14.7	N vs. C, C-E, C-L*
SF-36 PCS	BL	40.4±9.8	33.8±13.2	33.8±9.7	34.3±9.3	33.2±10.5	N vs. C, C-L*
	2 y	41.2±11.8	41.1±11.5	41.0±13.0	41.0±11.5	40.9±13.5	None
	Δ	0.9±6.7	7.1±10.4	6.6±11.1	6.0±11.7	7.5±10.6	N vs. C*
SF-36 MCS	BL	49.7±10.1	43.8±15.2	47.0±11.2	45.7±10.8	48.8±11.9	None
	2 y	49.6±13.1	48.4±12.6	50.3±11.0	48.0±12.2	53.7±8.2	None
	Δ	-0.1±8.9	5.0±13.9	3.3±8.8	2.7±8.5	4.2±9.4	None
SRS AC	BL	3.6±0.8	2.9±1.1	3.1±0.9	3.0±1.0	3.1±1.0	N vs. C, C-E*
	2 y	3.7±1.0	3.6±1.1	3.6±1.2	3.5±1.3	3.6±1.2	None
	Δ	0.1±0.7	0.6±0.8	0.5±1.0	0.4±1.0	0.5±1.1	None
SRS P	BL	3.2±0.9	2.4±1.0	2.4±0.8	2.4±0.8	2.5±0.8	N vs. C, C-E*
	2 y	3.2±1.1	3.3±1.2	3.4±1.2	3.3±1.3	3.6±1.1	None
	Δ	-0.0±0.6	1.0±1.2	1.0±1.2	0.9±1.1	1.0±1.2	N vs. C, C-E, C-L*
SRS AP	BL	3.1±0.8	2.4±0.7	2.59±0.7	2.7±0.7	2.5±0.6	N vs. C, C-L*
	2 y	3.1±0.9	3.6±0.9	3.5±1.0	3.4±0.9	3.7±1.1	N vs. C, C-L*
	Δ	-0.0±0.5	1.2±0.9	1.0±1.0	0.8±0.9	1.3±1.1	N vs. C, C-E, C-L*
SRS M	BL	3.7±0.7	3.3±1.1	3.7±0.9	3.8±1.0	3.7±0.9	None
	2 y	3.7±0.9	4.0±0.9	4.0±0.9	3.9±1.0	4.2±0.9	None
	Δ	0.0±0.7	0.6±0.8	0.2±0.7	0.0±0.6	0.5±0.8	O vs. C-E*
SRS S	BL	3.2±1.1	2.5±0.9	3.1±1.0	2.9±0.9	3.3±1.1	None
	2 y	3.6±0.9	4.3±0.9	4.2±1.0	3.9±1.2	4.5±0.5	N, O vs. C, C-L*
	Δ	0.4±1.1	1.7±1.3	1.2±1.4	1.0±1.6	1.3±0.9	N vs. C, C-L*
SRS T	BL	3.4±0.7	2.8±0.8	2.9±0.6	2.9±0.7	2.9±0.6	N vs. C, C-E, C-L*
	2 y	3.4±0.8	3.7±1.0	3.7±0.9	3.7±0.9	3.8±0.9	None
	Δ	0.1±0.4	0.8±0.7	0.7±0.8	0.6±0.8	0.8±0.8	N vs. C, C-E, C-L*

AC, activity; AP, appearance; M, mental; MCS, Mental Component Summary; ODI, Oswestry Disability Index; P, pain; PCS, Physical Component Summary; S, satisfaction; SF, Short-Form; SRS, Scoliosis Research Society; T, total.

Δ refers to the difference in the respective score from enrollment to 2-year follow-up.

* Statistically significant difference between each indicated patient group scores, to $p < .05$.

until she converted to operative treatment and designated a CROSS-Late patient. Despite minimal changes in alignment (PI-LL Δ : -2°), she displayed a larger deterioration in disability (ODI 52, Δ +6) at the time of conversion (Fig. 3, Middle). She underwent a T3-ilium fusion, and reported an ODI of 8 at 2-year follow-up, with improved sagittal and coronal spinopelvic alignment (Fig. 3, Right).

Discussion

Growing appreciation for the ASD's heterogeneity is met with debate directed at the role of radiographic evaluation in disease characterization and treatment decision making [3,31,32]. Mounting evidence solidifying correlations between global sagittal alignment and patient-reported pain/disability have prompted a gradual shift in paradigm regarding factors that drive symptomatology and a patient's decision to seek treatment. Minimizing ineffective and delayed medical care, large resource drains on the health-care system at the patient's detriment, is important in ASD, particularly in light of recent epidemiological population shifts [1]. This study is thus an assessment of self-reported disability and spinal deformity progressions of patients with ASD that crossover

(CROSS) from non-operative (NON) to operative (OP) care, and an investigation of clinical factors motivating this decision.

Patient-specific factors driving treatment selection for ASD have been previously explored [31,32]. Propensity score matched analysis of OP, NON, and CROSS groups in this study against variables associated with guiding treatment and overall outcomes (age, BMI, CCI) permitted equitable cohort comparison [33–35]. Consistent with previous reports, both radiographic and disability measures significantly motivated treatment conversion following matching. This study was novel in proposing measures that incorporated both clinical and radiographic features to profile these patients at first visit: NON patients meeting an ODI threshold designating severe disability (≥ 40) in combination with either coronal (thoracic/lumbar only, or both $>30^\circ$) scoliosis or markedly abnormal spinopelvic mismatch (PI-LL $\geq 20^\circ$) were at increased likelihood of converting to operative care. That conversion predictability from initial non-operative care hinged on the preliminary inclusion of an ODI threshold suggests that marked clinical disability is a prerequisite, surpassing pure radiographic evaluation, for informed ASD treatment recommendations. In comparing patients with ASD electing for operative or non-operative care, Fu et al. similarly noted worse

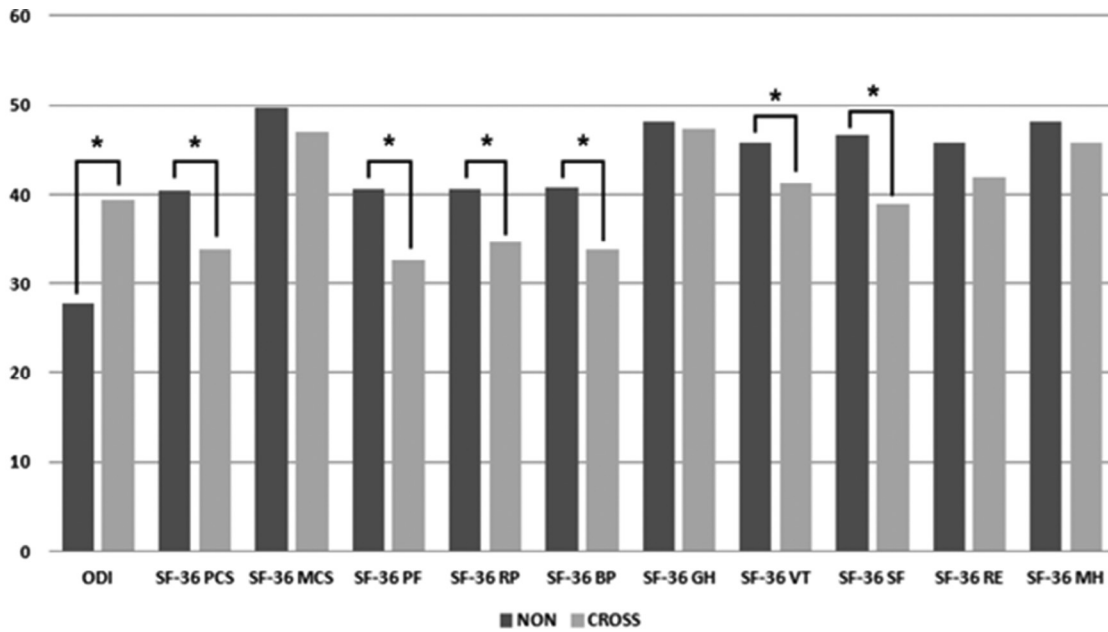


Fig. 2. Comparison of baseline patient-reported outcome measures (PROMs) scores for non-operative (NON), operative (OP), and crossover (CROSS) ASD patient groups for pain and disability. *Denotes statistical significance set to $p < .05$ between indicated patient groups. ODI, Oswestry Disability Index; SF, Short Form; PCS, Physical Component Summary; MCS, Mental Component Summary; PF, physical functioning; RP, role physical; BP, bodily pain; GH, general health; VT, vitality; SF, social functioning; RE, role emotional; MH, mental health.

ODI, SRS-30, and SF-36 scores among those opting for surgery [33]. The present findings are also sustained by Bess et al. who observed that patients with combined lumbar scoliosis and severe sagittal deformity ($SVA > 10$ cm) demonstrated the lowest PCS scores [36]. Importantly, these authors noted that by means of disability assessment through analogous disease comparison, delineating treatment guidelines and tailored health-care policy could be facilitated, given ASD’s heterogeneity at presentation.

Effectively profiling patients with ASD for proposed ODI/SRS-Schwab criteria may represent a new step in optimizing initial assessment for proper immediate treatment. Comparable efforts, including the development, validation, and implementation of SRS-Schwab ASD Classification itself have demonstrated clinical relevance in guiding treatment in practice [37–39]. The utilization of the ODI as a simple and easily

communicated instrument of assessing ASD’s clinical impact has also recently been correlated with specific spinal deformity parameters and age-groups, informing its potential additive use in patient profiling [40]. Moreover, these supplemental methods of screening patients with ASD may be advantageous to both surgeons and patients from economic and health-care related standpoints. Surgical ASD treatment has demonstrated cost-effectiveness through 10-year follow-up, conditional on pronounced PROM deterioration [41,42]. These findings may be reinforced, with possible reductions in expenditure, by more timely identification of those patients with ASD ultimately likely to select operative treatment. Patients also may benefit from early surgical treatment for prolonged optimization of PROMs, which drove the decision to seek operative treatment in this study. Although literature examining this hypothesis exists for other spinal diagnoses and report such advantages for sustained functional restoration, future studies analyzing this possibility in ASD are evidently pertinent.

The proposed patient profiling thresholds in this study were established based on differences between treatment groups at baseline visit and consistently sustained during the prospective 2-year evaluation. A defining feature of CROSS patients at first visit was a significantly greater self-reported pain and disability burden than NON. Although sagittal plane deformity is considered a main driver of disability, crossovers were only distinct in more pronounced spinopelvic mismatch compared with NON. Degenerative loss of lumbar lordosis is a well-understood mechanism driving progressive spinal malalignment, but this effect was not observed in this study [43,44]. The lack of sagittal or coronal deformity

Table 5

Radiographic and clinical variables significantly associated with increasing odds of a non-operative (NON) adult spinal deformity patient opting for treatment conversion (CROSS) following study enrollment

	NON	CROSS	OR	95% CI	p
ODI ≥ 40	31.0%	69.0%	3.2	1.2–8.3	.017
ODI ≥ 40 and Schwab T/L/D	30.4%	69.6%	3.1	1.1–8.6	.031
ODI ≥ 40 and Schwab PI-LL +/++	18.85	81.2%	5.6	1.5–21.5	.007

CI, confidence interval; D, double curve; L, lumbar curve; ODI, Oswestry Disability Index; OR, odds ratio; PI-LL, pelvic incidence minus lumbar lordosis; T, thoracic curve; NON, non-operative; CROSS, crossover.

Pearson χ^2 and binary logistic regression models were implemented to evaluate and generate predictors for CROSS likelihood.

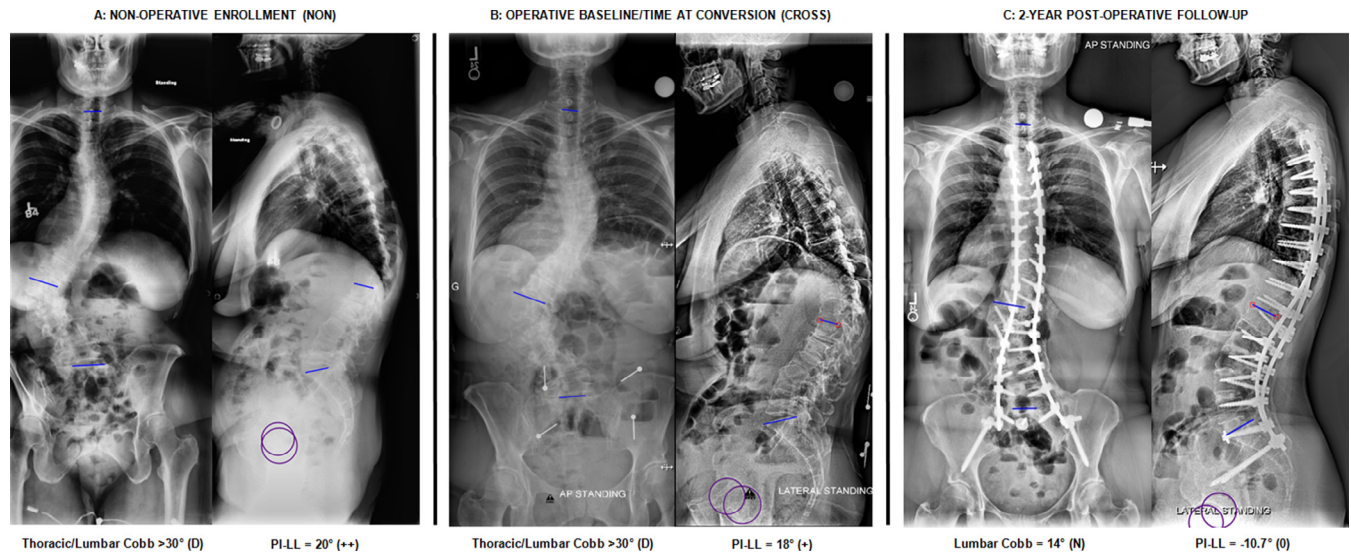


Fig. 3. Case example of a 54-year-old ASD female CROSS patient. Coronal/lateral radiographic provided at (Left) non-operative enrollment, (Middle) time of crossover/operative baseline, and (Right) 2-year postoperative follow-up.

progression from enrollment to conversion is likely due to this short interval in 59.5% of CROSS patients. Deciphering alignment deterioration as a cause of conversion would likely require a greater sample size and a more diverse population. The propensity score-matched analysis too, contingent on factors typifying severe spinal deformity, may have downplayed radiographic alignment decline as motivation for treatment crossover. However, this permitted a more refined understanding of how self-reported disability impacts a patient's decision making in the absence of worsened alignment.

Effectively, all CROSS patients displayed significant clinical deterioration by the time of operative conversion, with at minimum 7.5% meeting MCID in each category; timing-effect analysis also revealed increased degeneration in CROSS-Early (conversion <1 year) patients in ODI and multiple SRS-22r subscores at crossover, compared with CROSS-Late (>1 year) patients. These results reveal that ASD crossovers were significantly more impacted by their deformity than those who maintained conservative care. Although radiographic changes may drive the need for surgical correction, PROMs were more critical for patients and surgeons to seek surgical treatment.

Detecting pathophysiological factors precipitating these clinical deteriorations is beyond the scope of the present study. It is already well-established in the literature that untreated adult scoliosis can result in spinal stenosis with radiculopathy, muscle fatigue, and hip osteoarthritis associated with abnormal spinopelvic alignment, among other symptoms [45,46]. The exhaustion of physiological reserve with failed non-operative management may also prompt conversion to surgery. Importantly, the results of this study also speak to the unresolved efficacy of prolonged non-operative management for ASD: NON patients did not display significant changes or improvements in scores during the duration of follow-up. Conversely, transition to surgery resulted in sig-

nificant overall 2-year clinical improvements within crossover groups (CROSS, CROSS-Early/Late), as well as compared with NON. Additionally, CROSS patients' final 2 years' postconversion scores were similar to those of OP patients, highlighting the value of treating clinical disability, not solely radiographic deformity, in evolving ASD care. Although operative ASD correction inherently imparts a complication risk, this impact on health and disability is not necessarily lasting at extended follow-up [6,47,48]. Indeed, Glassman et al. noted that the risk of minor perioperative complications may not be as prohibitive in surgical treatment recommendations as once assumed because of minimal impact at 1-year postoperative [49].

Limitations

A primary limitation to this study is the lack of data regarding the method of non-operative treatment modalities before conversion, as differing forms of conservative care may be more effective in alleviating symptoms and delay the requirement for surgical correction. The patients in this study also represent those with more severe spinal deformity, prompting them to seek initial treatment at a surgical clinic in the first place, without adjustment for referral status, and thus these results may not be generalizable to all of spine deformity, especially those patients with mild or intermittent symptoms. In comparing non-operative and operative patients, less tangible baseline characteristics of either group influencing treatment modality may have introduced bias in operative and non-operative status. For example, patient social factors, time and financial availability, and treatment expectations were not available, and therefore may have been different between cohorts. Although this study indicates that certain patients initially receiving non-operative treatment for ASD may "cross over" to operative treatment, the retrospective, non-randomized

design of this study does not discount the utility of non-operative treatment for these patients.

Conclusions

Assessing patients with ASD that cross over from non-operative to operative treatment revealed that high baseline and increasing disability over time drove treatment conversion. Crossover patients achieved similar 2-year outcome scores as patients initially undergoing surgical deformity correction. The overall crossover rate in this study was 22%, with 60% converting to surgery within 1 year of prospective non-operative enrollment and care. Patients likely to elect for crossover can be profiled at first visit using established thresholds for detecting severe clinical disability and marked sagittal/coronal deformity. Profiling ASD cases at first visit for those patients at risk of crossover may optimize physician counseling and cost savings.

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