

Pain Trajectories Following Adolescent Idiopathic Scoliosis Correction

Analysis of Predictors and Functional Outcomes

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Background: A better understanding of early pain trajectories (patterns) following scoliosis surgery and how they relate to baseline patient characteristics and functional outcomes may allow for the development of mitigating strategies to improve patient outcomes.

Methods: This was a prospective cohort study. Adolescents with idiopathic scoliosis were recruited across multiple centers. Latent growth mixture modeling techniques were used to determine pain trajectories over the first postoperative year.

Results: The median numerical rating scale for pain in the hospital following surgery for adolescent idiopathic scoliosis was 5.0. It improved to 1.0 by 6 weeks, and was maintained at <1 by 3 to 12 months postoperatively. Three trajectories were identified, 2 of which involved moderate acute postoperative pain: 1 with good resolution and 1 with incomplete resolution by 1 year. The third trajectory involved mild acute postoperative pain with good resolution by 1 year. Membership in the “moderate pain with incomplete resolution” trajectory was predicted by higher baseline pain and anxiety, and patients in this trajectory reported worse quality of life than those in the trajectories with good resolution.

Conclusions: Pain recovery following surgery for idiopathic scoliosis was found to be substantial during the first 6 weeks and continued up to 1 year. We identified 3 main trajectories, 2 with favorable outcomes and 1 with persistent pain and worse quality of life at 1 year postoperatively. The risk factors most associated with the latter trajectory included increased baseline pain and anxiety.

Level of Evidence: Prognostic Level II. See Instructions for Authors for a complete description of levels of evidence.

Pain following scoliosis surgery has been studied extensively, but most often at discrete, acute, and/or remote time points that do not fully describe the overall pain experience. Trajectory modeling of repeated pain measurements, when used for groups of individuals with the same diagnosis or surgery, can aid in classifying individuals on the basis of different trajectories of pain resolution over time¹.

Sieberg and colleagues² identified 5 highly variable pain trajectories, with 5.8% of their patients following a persistent postoperative pain trajectory, the majority demonstrating good recovery, and 10.5% demonstrating delayed pain. Although that study provides valuable information regarding long-term pain outcomes following surgery for adolescent idiopathic scoliosis (AIS), its measurement schedule was limited to the preoperative

baseline followed by 1, 2, and 5 years postoperatively. The transition from acute to chronic postoperative pain has been reported as being between 2 to 3 months, suggesting that measurement during this early period is warranted³.

A better understanding of early pain trajectories following scoliosis surgery and associated functional outcomes would support practitioners in providing valuable clinical information to patients and families. Given the biopsychosocial nature of pain, an examination of modifiable psychological predictors of pain trajectories may allow for the development of a perioperative family-based intervention to improve pediatric patient outcomes^{4,5}. As such, we had 3 aims with the current study: (1) to describe postoperative pain trajectories for patients with AIS, (2) to examine parent and child psychological predictors of

Disclosure: The PORSCHE (Post-Operative Recovery following Spinal Correction: Home Experience) study was funded by the Canadian Institutes of Health Research. K.M. Bailey was funded by an award from the Maritime Strategy for Patient Oriented Research Support Unit. On the **Disclosure of Potential Conflicts of Interest** forms, which are provided with the online version of the article, one or more of the authors checked “yes” to indicate that the author had a relevant financial relationship in the biomedical arena outside the submitted work (<http://links.lww.com/JBJSOA/A266>).

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trajectory membership, and (3) to compare functional outcomes across identified trajectories.

Materials and Methods

This was a prospective cohort study.

Setting

The data presented in this manuscript are from the Post-Operative Recovery following Spinal Correction: Home Experience (PORSCHE) study, a large multicenter project examining the prevalence, predictors, and consequences of children's pain following scoliosis surgery.

Participants

Eligible participants included pediatric patients aged 10 to 20 years with AIS who were scheduled to undergo posterior scoliosis correction. This age range is comparable with that reported in similar studies^{4,6}. The indication for surgery was AIS with a progressive curve exceeding 40° to 45° in skeletally immature patients, and exceeding 50° to 55° in skeletally mature patients. Excluded were patients who did not speak English or whose parents did not speak English, who had a developmental delay or non-idiopathic scoliosis diagnosis, or who were classified as American Society of Anesthesiologists (ASA) III or higher or had notable surgical complications. Participants were not excluded for missing data.

This study received Research Ethics Board approval at all study sites.

Variables and Measures

All measures and the data collection schedule are presented in Table I.

Baseline demographic data collected included patient sex, age, and length of hospital stay.

Primary Outcome

Pain trajectories were formed on the basis of average pain assessment using a numerical rating scale (NRS). Patients were

verbally asked to rate their average pain over the past 24 hours using the NRS (0 to 10⁷, where 0 represents “no pain at all” and 10 represents “the worst pain you can imagine”).

Predictor Variables

Scores for the following measures were used as predictor variables: the State-Trait Anxiety Inventory-Child Form (STAIC)⁸, used to measure both state and trait anxiety (higher scores indicate greater baseline anxiety^{8,9}); the Pain Catastrophizing Scale-Child Form (PCS-C)¹⁰, a questionnaire designed to measure children's thoughts and feelings in response to pain (higher scores indicate a greater amount of “catastrophizing” in response to pain); the State-Trait Anxiety Inventory-Parent Form (STAIP)¹¹, assessing both the state and trait level of anxiety of the parent (higher scores indicate greater baseline anxiety); and the Pain Catastrophizing Scale-Parent Form (PCS-P)¹², a questionnaire designed to measure parents' thoughts and feelings in response to their child's pain (higher scores indicate a greater amount of “catastrophizing” in response to pain).

Secondary Outcomes

Secondary outcome measures were the Pediatric Quality of Life Inventory-version 4 (PedsQL-4), the Functional Disability Inventory (FDI), and the Scoliosis Research Society Health-Related Quality of Life Tool (SRS-30). The PedsQL-4¹³ is a questionnaire designed to measure the child's general quality of life (higher scores indicate greater quality of life). Scores of <78 are consistent with a clinically meaningful chronic health condition¹⁴. The FDI¹⁵ is used to assess the extent to which children experience difficulties completing specific physical tasks. This instrument has been used for children with chronic pain¹⁶⁻¹⁸ and postsurgical pain¹⁹. Scores of >12 indicate clinically meaningful disability²⁰. The SRS-30 consists of 30 items that measure scoliosis-specific health-related quality of life²¹⁻²⁷. There is no established clinical cutoff score for the SRS-30, but 0.23 is the minimum detectable measurement difference in the total score that indicates clinically meaningful differences between groups²⁸.

TABLE I Data Measurement Schedule Depicting When Measures Were Administered to Children and Their Parents

Measure	T0: Baseline	T1: In-Hospital	T2: 1st Wk at Home	T3: 4-6 Wk	T4: 3 Mo	T5: 6 Mo	T6: 12 Mo
Demographic information	X						
Numerical rating scale (NRS): average pain in last 24 hr	X	X	X	X	X	X	X
State-Trait Anxiety Inventory-Child Form (STAIC)	X						
Pain Catastrophizing Scale-Child Form (PCS-C)	X						
State-Trait Anxiety Inventory-Parent Form (STAIP)	X						
Pain Catastrophizing Scale-Parent Form (PCS-P)	X						
Pediatric Quality of Life Inventory-version 4 (PedsQL-4)							X
Functional Disability Index (FDI)							X
Scoliosis Research Society Health-Related Quality of Life Tool (SRS-30)							X

Procedure

Participants were identified and informed of the study by their attending surgeon at a preoperative visit, and a research assistant provided further information either in person or at a later time over the telephone, depending on the family's preference. Baseline measures were completed prior to surgery. Postsurgical measures were completed in-hospital, during the first week at home post-discharge, at 4 to 6 weeks postoperatively, and at 3, 6, and 12 months postoperatively. Data collection procedures were standardized across sites.

Statistical Methods

Preliminary analyses were performed using descriptive statistics to characterize the sample (Table II). Data were tested for normality, and statistical assumptions were inspected.

To identify pain trajectories, latent class growth analysis and latent growth mixture modeling (LGMM)^{29,30} using Mplus (version 8; Muthén & Muthén) were used. These statistical techniques identify multiple homogeneous subpopulations in a heterogeneous sample, determining meaningful classes of individual variation over time (i.e., trajectories). The details of these analytic techniques can be found elsewhere^{29,31}. This study utilized the adjusted Bayesian information criterion (BIC_a) and Akaike information criterion (AIC) as well as entropy values, a measure of probability regarding participant classification, to assess classification accuracy³². Overall fit was assessed with the bootstrapped Lo-Mendell-Rubin test (BLRT). We compared models with 1 to 4 trajectories for NRS ratings over time (in-hospital, first week at home, 4 to 6 weeks, and 3, 6 and 12 months). Because of the variability in data collection time points, baseline pain was not included as a trajectory time point, but given its importance for postsurgical pain, baseline pain was examined as a covariate in the trajectory model.

With respect to predictors of trajectory membership, a multinomial logistic regression analysis was conducted to identify psychological predictors of a persistent pain trajectory. Baseline psychosocial factors (child and parent pain catastrophizing, child

state and trait anxiety) were entered as independent variables to predict trajectory class as the dependent variable, accounting for age and sex.

Comparison of Functional Outcomes Across Trajectories

Data for the 12-month functional outcomes were not normally distributed, so transformations were applied, which improved the distribution of the variables and their residuals. A multivariate analysis of variance (MANOVA) was conducted to examine the relationship between trajectory membership and participants' scores on the 3 functional outcomes (FDI, PedsQL-4, and SRS-30). MANOVA results obtained with the transformed variables were consistent with those obtained using the untransformed variables. Given the missing data in the 12-month outcomes, we conducted multiple imputation modeling with 40 imputations using the Markov chain Monte Carlo algorithm available in SPSS version 25.0 (IBM), with auxiliary variables identified using the Missing Data Analysis function, to validate the MANOVA findings. For interpretability, results of analyses of raw (non-imputed) data are presented.

Results

Participants

Of 267 potential participants, across all 8 participating sites, consent for study participation was received for 246. A total of 220 participants completed at least some part of the baseline (T0) assessment (Fig. 1). The retention rates for each time point are as follows: first week home, 89%; 4 to 6 week follow-up, 89%; 3-month follow-up, 67%; 6-month follow-up, 70%; and 12-month follow-up, 63%. There were no significant differences between the participants who did and did not complete the study at 12 months with respect to baseline measures, with the exception of length of hospital stay: the average hospital stay for those who completed the study was less than that of those who did not complete the study (mean [and standard deviation] of 5.6 ± 1.3 days compared with 6.2 ± 1.6 days).

TABLE II Descriptive Data and Correlations Between Baseline Variables*

Variable		Correlations with Other Variables: Kendall R										
No.	Description	Mean	SD	Range	1	2	3	4	5	6	7	8
1	Age in yr	14.60	1.87	10-20	—	-0.19†	-0.01	0.03	0.08	0.14‡	0.10	0.07
2	% female	86%	—	—	—	—	-0.02	0.09	-0.05	0.02	0.05	-0.11
3	Length of hospital stay in days	5.8	1.4	3-12	—	—	—	0.03	0.07	0.10	0.001	-0.01
4	Baseline NRS	2.8	2.3	0-9	—	—	—	—	0.24†	0.13‡	0.22†	0.08
5	PCS-C	18.7	9.6	0-44	—	—	—	—	—	0.24†	0.33†	0.04
6	Child state anxiety	34.5	7.5	6-56	—	—	—	—	—	—	0.37†	0.04
7	Child trait anxiety	34.9	7.3	9-57	—	—	—	—	—	—	—	0.09
8	PCS-P	22.2	9.1	0-52	—	—	—	—	—	—	—	—

*SD = standard deviation, NRS = numerical rating scale, PCS-C = Pain Catastrophizing Scale-Child Form, and PCS-P = Pain Catastrophizing Scale-Parent Form. †P < 0.01. ‡P < 0.05.

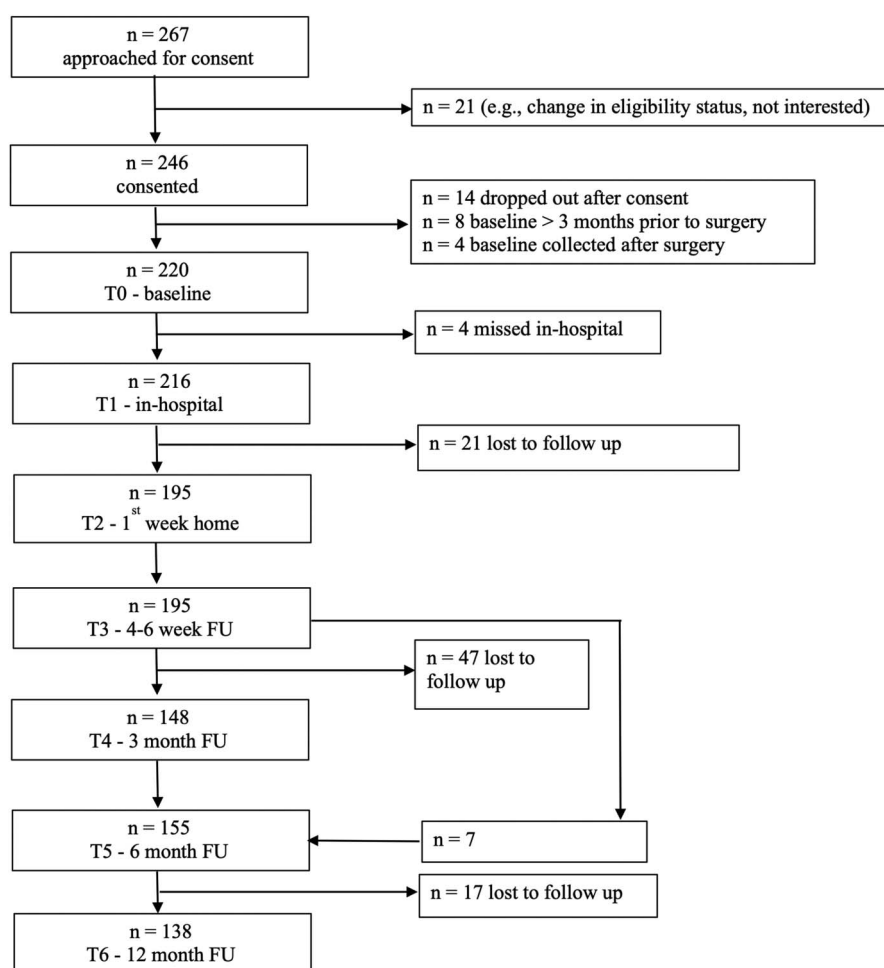


Fig. 1
Participant recruitment and study flow. FU = follow-up.

Demographic and Clinical Variables

The final sample included 220 children. Descriptive statistics and correlations between baseline variables are presented in Table II. The median NRS ratings (with the interquartile

range) were as follows: baseline, 2.75 (1.00 to 5.00) ($n = 202$); in-hospital, 5.00 (4.00 to 6.50) ($n = 216$); first week at home, 3.00 (2.00 to 4.50) ($n = 195$); 4 to 6 weeks, 1.00 (0.00 to 2.00) ($n = 195$); 3 months, 0.00 (0.00 to 1.00) ($n = 148$);

TABLE III Fit Indices Used to Determine the Final Trajectory Model*

Model	AIC	BIC _a	BLRT P Value	Latent Class Probability Range	Entropy	Sample Size per Trajectory Based on Most Likely Membership
1 trajectory	3,622.94	3,626.08	—	1.0	—	220
2 trajectories	3,687.19	3,690.56	<0.001	0.92-0.98	0.902	189/31
3 trajectories	3,628.61	3,632.65	<0.001	0.84-0.90	0.700	75/28/117
4 trajectories	3,594.92	3,599.64	<0.001	0.84-0.99	0.769	71/28/116/5
3 trajectories with baseline pain covariate†‡	3,293.51	3,296.59	<0.001	0.87-0.93	0.740	78/26/98

*AIC = Akaike information criterion, BIC_a = adjusted Bayesian information criterion, and BLRT = bootstrapped Lo-Mendell-Rubin test. †Model with the best fit to the data that respected all criteria (lower AIC and BIC_a values, smallest trajectory with $n > 5\%$, adequate classification accuracy). ‡Addition of baseline pain as a covariate resulted in an adjusted sample size of $n = 202$.

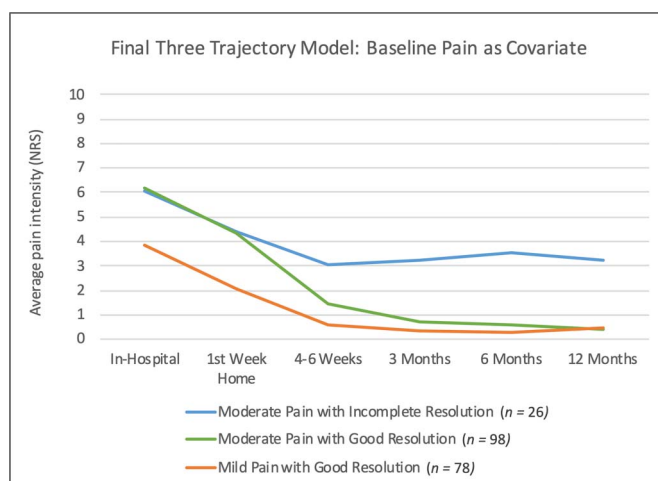


Fig. 2

The final model with 3 pain trajectories and baseline pain as a covariate. NRS = numerical rating scale.

6 months, 0.00 (0.00 to 1.00) (n = 155); and 12 months, 0.00 (0.00 to 1.00) (n = 138).

Determination of Pain Trajectories

Using iterative LGMM modeling, 4 models were tested with and without a covariate (Table III). The trajectories were named using established adult NRS cutoffs. Because of the improvements observed in the fit indices when compared with other trajectory models without a covariate, baseline pain was retained as a covariate in the final model (Fig. 2). The covariate adjustment resulted in a model with n = 202. Three trajectories were identified, 2 of which involved moderate acute postoperative pain: 1 with good resolution and 1 with incomplete resolution by 1 year. The third trajectory involved mild acute postoperative pain with good resolution by 1 year. Greater baseline pain increased the odds of membership in the “moderate pain with incomplete resolution” trajectory 1.5-fold compared with the “moderate pain with good resolution” trajectory.

Prediction of Trajectory Membership

The results of the multinomial regression analysis predicting group membership are shown in Table IV. No differences in predictors were observed between the 2 trajectories with good pain resolution. When using the “mild pain with good resolution” trajectory as the reference class, child trait anxiety increased the odds of being classified in the “moderate pain with incomplete resolution” trajectory, and female sex increased the odds of being classified in the “moderate pain with good resolution” trajectory.

Functional Outcomes Associated with Each Trajectory

The MANOVA indicated significant differences in functional outcomes between trajectory groups ($F[6,246] = 4.34$, $p < 0.001$; Wilk lambda = 0.82, partial $\eta^2 = 0.10$, $d = 0.98$). Group differences in each of the functional outcomes are presented in Figures 3-A, 3-B, and 3-C. Members of the “moderate pain with incomplete resolution” trajectory had significantly worse functioning on all measures compared with the other 2 trajectories, but clinically relevant differences were observed only for the quality-of-life measures (SRS-30, PedsQL-4). While there were significant differences between groups on the FDI, all trajectory groups demonstrated little to no clinically relevant functional disability (FDI) at 12 months.

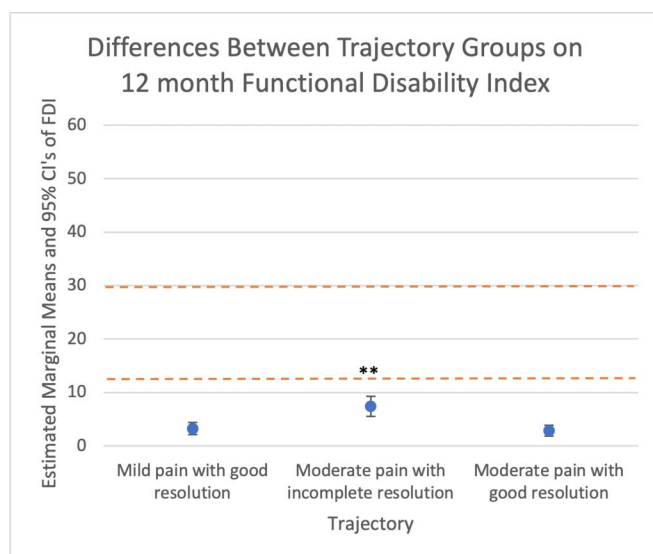
Discussion

Using LGMM³⁰, we identified 3 distinct postoperative pain trajectories following scoliosis correction for patients with AIS, with baseline pain included as a covariate to improve model fit. Nearly half of the sample followed a postoperative trajectory characterized by moderate to severe pain in the immediate postoperative period that sharply declined over the first few weeks and stabilized to mild or no pain by 12 months (n = 98). A second trajectory was characterized by mild to moderate pain in the immediate postoperative period that gradually declined over the first few weeks and stabilized to mild or no pain by 12 months (n = 78). A small subset of the sample followed a postoperative trajectory characterized by

TABLE IV Multinomial Logistic Regression Showing the Relationship Between Baseline Predictors and Group Membership in Pain Trajectories*

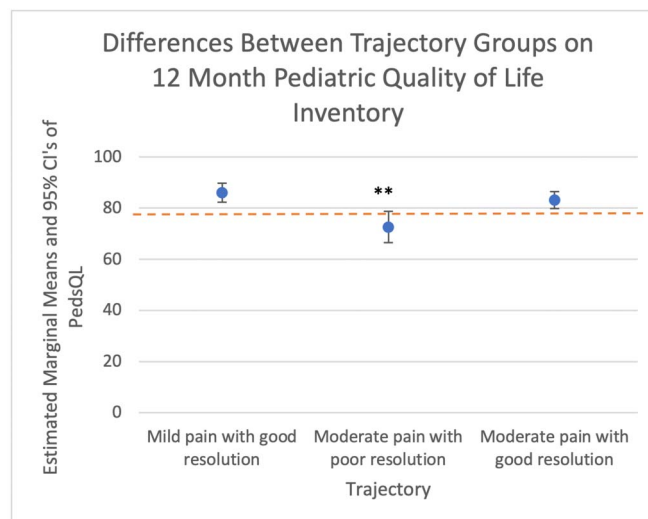
Predictor	“Moderate Pain with Incomplete Resolution” Vs. “Mild Pain with Good Resolution”			“Moderate Pain with Good Resolution” Vs. “Mild Pain with Good Resolution”		
	Beta (SE)	Wald	Odds Ratio (95% CI)	Beta (SE)	Wald	Odds Ratio (95% CI)
Child age	-0.18 (1.54)	1.33	1.20 (0.88-1.62)	0.11 (0.11)	0.92	1.11 (0.90-1.38)
Child sex	-0.95 (0.87)	1.21	0.39 (0.07-2.11)	-1.1 (0.54)†	4.14	0.33 (0.12-0.96)
Child PCS	-0.006 (0.03)	0.04	1.00 (0.93-1.06)	0.02 (0.02)	0.98	1.02 (0.98-1.07)
Child state anxiety	0.04 (0.05)	0.61	1.04 (0.95-1.13)	-0.05 (0.03)	2.11	0.95 (0.89-1.02)
Child trait anxiety	0.12 (0.05)†	5.34	1.12 (1.02-1.24)	0.06 (0.03)	2.78	1.06 (1.00-1.13)
Parent PCS	-0.06 (0.03)	3.46	0.94 (0.88-1.00)	-0.04 (0.02)	2.98	0.96 (0.92-1.00)

*SE = standard error of beta, and CI = confidence interval. Child sex was coded as 1 for female and 0 for male. $R^2 = 0.15$ (Cox and Snell), 0.18 (Nagelkerke). Model $\chi^2(12) = 26.00$; $p < 0.05$. † $p < 0.05$.



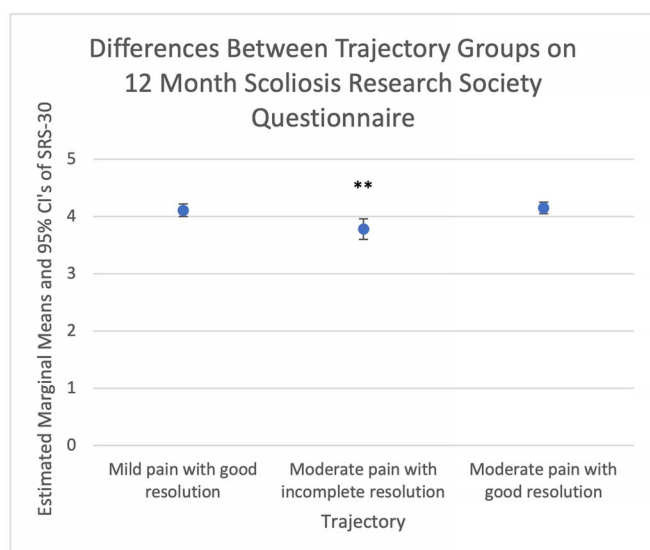
$F(2, 125) = 9.30; p < 0.0001$; partial $\eta^2 = .13$; *Cohen's d* = .98
 FDI – Functional Disability Index
 Clinical Cutoffs – 0-12 = None/Mild, 13-29 = Moderate, ≥ 30 = Severe
 ** $p < 0.01$

Fig. 3-A



$F(2, 125) = 6.92; p < .001$; partial $\eta^2 = .10$; *cohen's d* = .92
 PedsQL – Pediatric Quality of Life
 Clinical Cutoff - Chronic Illness population: < 78
 ** $p < 0.01$

Fig. 3-B



$F(2, 125) = 6.32; p < .01$; partial $\eta^2 = .09$; *Cohen's d* = .89
 SRS – Scoliosis Research Society Questionnaire
 No Available Clinical Cutoffs
 ** $p < 0.01$

Fig. 3-C

moderate to severe pain in the immediate postoperative period that gradually declined over the first few weeks and then stabilized to moderate pain that remained at 12 months ($n = 26$). Among potential psychological predictors, anxiety increased the odds of membership in this trajectory, as did greater baseline pain. Patients in this trajectory also reported statistically significant and clinically relevant worse quality of life at 12 months compared with patients in the other trajectories. While significant differences in the FDI were also found between trajectories, it

Figs. 3-A, 3-B, and 3-C Differences between trajectory groups in 12-month functional outcomes as measured using the Functional Disability Index (**Fig. 3-A**), the Pediatric Quality of Life Inventory (**Fig. 3-B**), and the Scoliosis Research Society Health-Related Quality of Life Tool (SRS-30) (**Fig. 3-C**). The dashed lines indicate the clinical cutoff values. CI = confidence interval.

should be noted that all patients reported functional disability ratings suggestive of little to no disability at 12 months.

Baseline pain was found to improve trajectory model fit and increase the odds of following a persistent pain trajectory. However, questions still remain as to whether the pain experienced in this group should be thought of as chronic postsurgical pain or unresolved baseline pain. According to the definition of chronic postsurgical pain as described by Macrae and Davies³, the pain must develop after surgery, and any

preexisting problems possibly causing the pain should be excluded. Future studies that utilize a more nuanced measure of pain (e.g., quality, exact location) are needed to differentiate baseline pain from pain reported in the postoperative period as well as to define a threshold for intervention. Nevertheless, findings from this study suggest that the assessment and treatment of baseline pain is important for postoperative outcomes.

Neither parent nor child catastrophizing in response to pain was predictive of trajectory membership. This finding could be related to the measurement tool itself, which does not incorporate a social and/or developmental context of cognition, nor threat appraisal, into its catastrophizing assessment³³. In addition, it has been shown that the relationship between catastrophizing and pain intensity is moderated by age, being stronger in adults than in children/adolescents³⁴. It is also possible that baseline catastrophizing is no longer a stable measure in adolescents after experiencing a major surgery³⁵.

In the current study, patients with moderate immediate postoperative pain followed 2 trajectories—good and incomplete resolution—that suggested the influence of factors other than baseline pain and anxiety as being predictive. In particular, it may be important to examine potential risk factors (e.g., return to sports, pain catastrophizing, emotion regulation, and anxiety) and potentially intervene between 4 to 6 weeks, when these trajectories begin to diverge. Katz³⁶ suggested that different factors may contribute to the transition from acute to chronic postsurgical pain than contribute to the persistence of chronic pain, including those that relate to adolescent development (e.g., emotional regulation) or are associated with spinal deformity (e.g., concerns with body image).

Adolescents in the “moderate pain with incomplete resolution” trajectory reported lower quality of life at 12 months compared with participants in the other trajectories. These results are consistent with those of Rabbitts and colleagues⁴, whose “late recovery” pain trajectory in a mixed orthopaedic sample was associated with lower health-related quality of life at 12 months. As in their study, our results also support the notion that moderate immediate postsurgical pain alone does not necessarily lead to poor functional outcomes, but the persistence of pain in the longer term may be more salient. Consequently, appropriate pain management over the longer term should also be emphasized.

The findings of the current study should be considered in light of several limitations. First, this study only measured pain up to 12 months postoperatively. Whereas our study demonstrated important changes in pain trajectories over the course of 12 months, the study by Sieberg and colleagues² suggested that pain trajectories continue to evolve in important ways beyond the first postoperative year. As such, the conclusions drawn in this study can only be applied to pain in the first postoperative year and may not apply to pain or functional outcomes in the longer term.

An additional limitation relates to the labeling of the pain trajectories, as adult NRS cutoffs were used. More research involving pediatric populations is needed to determine the most appropriate cutoffs in a pediatric postsurgical population.

Another important limitation in this study concerns participants who dropped out of the study before the 12-month

time point. In order to counteract the effects of missing data, the LGMM data-analysis method used employs a robust full-information maximum-likelihood (FIML) estimation procedure for handling missing data and assumes that the missing data can be predicted from other variables in the model (missing at random)³⁷. LGMM is very well suited to data sets that have missing data because FIML estimation is considered one of the most robust methods for dealing with it. Additionally, multiple imputation modeling was used to verify the results of the MANOVA for functional outcomes^{38,39}.

A final limitation is related to the scope of factors used to predict trajectory membership. We examined parent and child psychological factors and baseline pain as predictors of trajectory membership in order to potentially inform the development of a psychological preoperative intervention. Future studies should examine other factors (e.g., baseline function, return to sports, radiographic details, number of fusion levels, and pain management protocols) as predictors of an unfavorable pain trajectory that could also be used to identify patients and mitigate risk.

In conclusion, pain recovery following scoliosis surgery in adolescents typically occurs within the first 6 weeks and is maintained up to 12 months postoperatively. In this study, we identified 3 trajectories, 2 with favorable outcomes and 1 with persistent pain at 12 months postoperatively. The risk factors most associated with the latter trajectory included increased baseline pain and child anxiety. This trajectory also was associated with worse results on quality-of-life measures. Future research should examine additional risk and protective factors associated with these pain trajectories as well as the functional outcomes for this population, with a view to developing mitigating strategies. ■

Note: The authors acknowledge the Canadian Pediatric Spinal Deformity Study Group and the PORSCHE Study Group for their support of this project. The authors also thank Dr. Sean MacKinnon for consulting on the statistical analyses and Mr. Gilanders Unger for assistance with data management.

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