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ORIGINAL ARTICLE

Back pain in adolescents with idiopathic scoliosis: the contribution of morphological and psychological factors

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Abstract

Purpose To define the relationship between 3D radiological features, psychological factors, and back pain prevalence and intensity in patients with adolescent idiopathic scoliosis (AIS).

Methods Consecutive AIS patients answered self-reported questionnaires and underwent simultaneous posterior–anterior and lateral scans of the spine (EOS Imaging, Paris, France). 3D reconstructions of the spine and pelvis reported 18 parameters in the coronal, sagittal, and axial plane.

Results Hundred and twenty-four patients with AIS were included in the study. Overall, 90% of AIS patients reported having some back pain over the last 6 months and 85.8% over the last 30 days. Pain intensity in the last month was reported to be mild in 37.5%, moderate in 31.8%, moderate to severe in 24.3%, and severe in 6.54% of cases. Location of back pain was associated with location of main curve ($P=0.036$). Low back pain was associated with higher lumbar apical AVR and lower lumbar lordosis ($P<0.05$). Independent risk factors for back pain in AIS were pain catastrophizing ($B=0.061$, $P=0.035$), poorer self-reported state of mental health ($B=-0.872$, $P=0.023$), decreased thoracic kyphosis ($B=-0.033$, $P=0.044$) and greater pelvic asymmetry ($B=0.146$, $P=0.047$). There was a significant association between self-reported pain intensity in the last 24 h and levels of catastrophizing. Pain catastrophizing level influenced the relationship between deformity severity and pain intensity. In low catastrophizers, there was a significant association between greater deformity severity and higher pain levels.

Conclusions Back pain in AIS is multifactorial and associated with psychological and morphological parameters. Pain catastrophizing is an important construct in AIS-related pain and should be taken into consideration when evaluating these patients.

Keywords Scoliosis · Back pain · Pain catastrophizing · Anxiety · Adolescents · Pain · Spine

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Introduction

Back pain is a common complaint in patients with adolescent idiopathic scoliosis (AIS). We recently identified that a relatively high proportion of AIS patients with chronic back pain have functional disability, sleep disorders, and reduced quality of life [1]. However, pain is frequently underestimated by surgeons who treat these patients [2]. Indeed, AIS was considered to be a painless condition until a few decades ago [3]. Main reasons for skepticism towards an association between pain and deformity include the current controversy in the literature on the link between deformity severity and pain intensity [4–8], and the more convincing statistical association between other psychological variables (i.e., self-image or mental health state) and pain [2, 9]. In fact, it is common that patients with small curves present with intense pain and vice-versa, suggesting that morphology is not the only explanation for the association.

Despite the evolvement of pain research in recent years with demonstration of advanced cartilage deterioration in AIS as seen in osteoarthritis [10], and the evidence of impaired endogenous pain modulation in around 50% of AIS patients with chronic back pain [1], there is a lack of comprehensive data investigating the contribution of morphological and psychological factors for back pain in this population. For example, although recognized as a three-dimensional deformity, there are no studies investigating the relationship between vertebral axial rotation and pain in this population. In adults with scoliosis, vertebral axial rotation is significantly associated with pain [11, 12]. In AIS, there is growing evidence suggesting that similar curve types can have different axial plane patterns [13], and the axial plane pattern may predict outcomes of AIS [14].

Moreover, there is a lack of studies investigating the role of psychological and behavioral processes between pain and AIS. For example, the use of specific self-reported instruments to measure mood and pain catastrophizing has not been reported. Pain catastrophizing is defined as an exaggerated negative mindset toward actual or anticipated pain, characterized by magnification, rumination, and helplessness [15]. Pain catastrophizing is a strong predictor of self-reported pain intensity and disability in adults [16] and children [17–21]. In fact, there is evidence suggesting that pain catastrophizing in children is a significant predictor of persistent pain and central sensitization in adulthood [18, 22]. To date, there is no study assessing the effect of pain catastrophizing on pain in these patients.

In order to better understand the relationship between the morphological aspects of AIS and back pain, we designed a pain study incorporating three-dimensional radiological assessment and comprehensive psychological measures related to pain processing. We hypothesized that back pain reported by AIS patients is related to morphological factors, as well as psychological parameters.

Methods

A cross-sectional study was designed and comprised of 124 consecutive AIS patients aged between 10 and 21 years old prior to elective spinal surgery at the Shriners Hospitals for Children—Canada. Pain was not a primary indication for scoliosis surgery. Patients were approached by a research assistant during the preoperative consultation and prospectively enrolled in the study after signing an informed consent. Exclusion criteria were inability to speak English or French, a diagnosis of developmental delay that would interfere with completing the questionnaires (e.g., mental development delay), and previous spine surgery. A research assistant collected information on demographics, medical history, and self-reported questionnaires for each enrolled patient 7 to 10 days before surgery.

Ethics approval was obtained prior to the beginning of the recruitment from the Research Ethics Board of our Institution (A08-M71-17B).

Self-reported measures

Self-reported pain intensity in the last 24 h was assessed using the Numerical Rating Scale (NRS 0–10), where 0 indicated no pain and 10 indicated the worst pain imaginable. Patients were asked to give the worst pain (NRS-worst pain), average pain (NRS-average pain), and best pain (NRS-best pain) in the last 24 h. The NRS has been validated in the pediatric population and is recommended for use in clinical research [23, 24]. The location of pain was reported in a body outline diagram of the back divided into several segments completed by the patient [1].

The preoperative questions of the Scoliosis Research Society—30 (SRS30) were used to evaluate health-related quality of life [25]. The questionnaire is composed of 5 domains as follows: function/activity (SRS30 function), pain (SRS30 pain), self-image/appearance (SRS30 self-image), mental health (SRS30 mental health), and satisfaction with management (SRS30 satisfaction). Each domain is graded from 1 (worst) to 5 (best).

The Pain catastrophizing scale for children (PCS-C) evaluates rumination, magnification, and helplessness dimensions of pain catastrophizing [20, 26]. Based on levels of functional disability, depression and anxiety, different clinical reference points for PCS-C have been suggested: low catastrophizing, score between 0 and 4; moderate

catastrophizing, score between 15 and 25; and high catastrophizing, score ≥ 26 [27].

The State and Trait Anxiety Inventory for children (STAI-c) was used to assess anxiety [28, 29]. This inventory is composed of 2 subscales: State Anxiety Scale (20 items), which evaluates the current state of anxiety, measuring subjective feelings of apprehension, tension, nervousness, worry, and activation/arousal of the autonomic nervous system; and the Trait Anxiety Scale (20 items), which assesses anxiety proneness, including general states of calmness, confidence, and security [30].

Radiological assessment

Each participant underwent simultaneous posterior–anterior and lateral scans of the spine, including cervical spine and femoral heads in standing position in the EOS apparatus (EOS Imaging, Paris, France). Stereoradiographs were performed in a standard protocol which included free-standing position with horizontal gaze, with their hands lifted and placed flat on the wall at chest height in order to clear the thoracic spine adequately. 3D reconstructions of the spine and pelvis were performed by experienced professionals trained at the EOS Imaging (Montreal, Canada) using SterEOS software version 1.6.4.7977 (EOS Imaging) and not involved with patient's care or administration of questionnaires. All parameters were expressed in the patient's reference plane based on a vertical plane passing through the center of the acetabulum, in order to correct the effects of a potential axial rotation of the pelvis during image acquisition [31].

From the 3D reconstructions, 18 parameters were assessed in the coronal, sagittal, and axial plane. From the coronal plane the following variables were extracted: Cobb angle of the proximal thoracic, main thoracic and thoracolumbar/lumbar, as well as the major Cobb angle (defined as the largest measure), thoracic apical translation, lumbar apical translation, pelvic asymmetry (i.e., functional leg length discrepancy [LLD], measured as the difference between both height of the femoral heads in mm) [32], and coronal balance (defined as the difference between the thoracic and lumbar apical translations). From the sagittal plane, we extracted sagittal vertical axis (SVA), T1-T12 kyphosis, L1-S1 lordosis, pelvic incidence (PI), sacral slope (SS), and pelvic tilt (PT). Axial plane parameters included the apical vertebral axial rotation (AVR), and the axial intervertebral rotation (AIR) of the upper and lower levels of the main curve, defined as the absolute sum of intervertebral rotations from the upper neutral vertebra to the apical vertebra, and from the apical vertebra to the lower neutral vertebra, respectively [33]. We also evaluated the torsion index of the main curve, defined as the absolute sum of the axial intervertebral rotation of the curve [33, 34]. SterEOS 3D software is currently the most precise and accurate method for measurement of vertebral axial rotation with an error of 2.4° on average [35]. Finally, Lenke classification was determined to describe the curve types [36].

Data analysis

Statistical analyses were conducted with SPSS 20 (IBM Statistics). Sample size was calculated to detect a small correlation between radiological variables (i.e., Cobb angle) and pain intensity [37]. Thus, a sample of 124 individuals provided 92% of power to detect a correlation of 0.3 (moderate effect size) with 5% of level of significance. Categorical variables were presented as percentages. Continuous variables were submitted to the Kolmogorov–Smirnov test to evaluate normal distribution and were presented as mean ± standard deviation, median and interquartile range.

Similar to Djurasovic et al. [38], we divided the patient cohort into two groups based on the value of their preoperative SRS pain domain score. Patients with a preoperative pain domain score of 1 (severe), 2 (moderate to severe), or 3 (moderate) were categorized as painful scoliosis, whereas patients with a pain domain score of 4 (mild) or 5 (none) were categorized as the nonpainful scoliosis group. We compared the radiological and self-reported measures of patients reporting moderate to severe back pain over the last 30 days (pain group, $N = 69$) and those reporting minimal or no back pain (no pain group, $N = 55$) [38].

Comparisons between groups were conducted with chi-square tests for categorical variables, and Student t test or Mann–Whitney test for continuous variables, according to the distribution. Radiological parameters with P value less than 0.2 were included in the initial model of the logistic regression together with pain catastrophizing, trait anxiety, SRS30 self-image, and SRS30 mental health. Stepwise logistic regression using backward elimination method was applied to select the final model with independent variables associated with group membership (pain vs no pain group), which included only variables with $P < 0.05$.

In order to evaluate the overall contribution of radiological and psychological variables to the group membership, we conducted different multivariate logistic regressions. Discrimination ability was assessed using area under the ROC (receiver operating characteristic) curve for each model [39]. First, we assessed the discrimination ability of each radiological plane: axial plane model (AVR apical proximal thoracic, AVR main thoracic, AVR thoracolumbar/lumbar, torsion index), coronal plane model (Cobb proximal thoracic, Cobb main thoracic, Cobb thoracolumbar/lumbar, apical translation thoracic, apical translation lumbar, coronal balance, pelvic asymmetry), sagittal plane model (SVA, T1-T12 kyphosis, L1-S1 lordosis, PI, PT), and combinations. Finally, the discrimination ability of a biomechanical model

with variables obtained by the SterEOS 3D reconstructions as well as a psychological model with pain catastrophizing and anxiety were tested.

Pearson correlation coefficient was used to assess the relationship between self-reported measures. Self-reported pain intensity according to the level of catastrophizing was evaluated using ANOVA with Bonferroni post-hoc tests. Preliminary analyses demonstrated significant association between catastrophizing and pain intensity. In order to assess the relationship between radiological parameters, catastrophizing and pain intensity, interaction terms between pain catastrophizing and the radiological variables were created. Multiple models of linear regressions were used to assess the association between radiographic parameters and pain intensity (NRS-average pain). First, we included in each model the interaction term and the main variables (pain catastrophizing and radiographic parameter). If the interaction was not statistically significant, it was then removed and the main effect of the variable was evaluated. Scatter plots with predicted values of pain intensity and the radiological variable according to different catastrophizing levels (PCS-C: low, 0–14; moderate, 15–25; and high, ≥ 26 [27]) were used to interpret the statistical interactions.

Results

Sample

A total of 124 patients with AIS were included in the study. Table 1 presents the demographic features of the sample. Radiographic parameters are summarized in Table 2. Curve types were most commonly Lenke 1 (main thoracic = 39.5%) or Lenke 2 (double thoracic = 26.6%) followed by Lenke 5 (thoracolumbar/lumbar = 12.9%), Lenke 6 (thoracolumbar/lumbar—main thoracic = 9.7%), Lenke 4 (triple major = 6.5%), and Lenke 3 (double major = 4.8%). From the 108 patients with a structural thoracic curve, only 4 (3.2%) had a left thoracic curve.

Table 1 General characteristics of the patients (data are presented as mean ± standard deviation or percentage)

	Total ($N = 124$)	Pain ($N = 69$)	No Pain ($N = 55$)	P values
Female	75.8%	76.1%	73.6%	0.750*
Age	15.2 (± 2.07)	15.4 (± 1.97)	15.0 (± 2.25)	0.357**
Height	162.3 (± 9.21)	162.9 (± 8.13)	161.7 (± 10.6)	0.483**
Weight	56.4 (± 14.9)	57.2 (± 12.1)	53.3 (± 9.49)	0.126***
BMI	20.9 (± 3.48)	21.4 (± 4.01)	20.1 (± 2.50)	0.081***

*Chi-square, **Student unpaired t test, ***Mann–Whitney test for group comparisons

Table 2 Tridimensional radiographic parameters of AIS patients ($N = 124$)

	Mean (± SD)	Median	P25–P75
Coronal plane			
Cobb proximal thoracic (°)	24.5 (± 10.8)	23.9	16.2–32.0
Cobb main thoracic (°)	52.3 (± 14.2)	53.3	44.13–60.7
Cobb thoracolumbar (°)	40.4 (± 15.7)	38.5	29.8–53.2
Cobb major curve (°)	55.5 (± 11.9)	54.5	48.7–62.0
Apical translation thoracic (mm)	36.0 (± 17.1)	37.0	25.0–48.0
Apical translation lumbar (mm)	19.0 (± 18.0)	14.0	3.25–32.7
Lateral pelvic tilt (mm)	4.48 (± 3.39)	4.00	1.39–6.55
Coronal balance (mm)	14.5 (± 11.3)	13.0	5.00–23.0
Sagittal plane			
SVA (mm)	− 1.41 (± 22.6)	0.1	− 16.5–13.75
T1-T12 kyphosis (°)	27.8 (± 17.2)	27.9	17.7–38.6
L1-S1 lordosis (°)	57.9 (± 15.0)	57.7	48.5–66.3
Pelvic incidence (°)	52.5 (± 13.2)	52.0	44.1–60.5
Sacral slope (°)	44.8 (± 10.8)	46.8	39.1–51.0
Pelvic tilt (°)	7.65 (± 8.12)	7.74	2.39–11.31
Axial plane			
AVR apex major curve (°)	16.9 (± 9.68)	16.0	10.0–22.2
AIR upper major curve (°)	21.8 (± 8.35)	21.0	16.7–26.0
AIR lower major curve (°)	12.4 (± 6.60)	11.0	8.0–16.0
Torsion index (°)	35.0 (± 11.5)	34.6	27.3–40.2

SD standard deviation, *P* percentile, *SVA* sagittal vertical axis, *AVR* axial vertebral rotation, *AIR* axial intervertebral rotation

Back pain prevalence and associated factors

Overall, 90% of AIS patients reported having some back pain over the last 6 months and 85.8% over the last 30 days. Pain intensity in the last month was reported to be mild in 37.5%, moderate in 31.8%, moderate to severe in 24.3%, and severe in 6.54%. Overall, 20.8% reported not having pain at rest or rarely experiencing it (27.5%). Medication use for back pain was reported by 25% of the cohort, with 5.64% reporting opioid use.

Back pain was located in the upper or lower thoracic spine in 61.5%, lower back in 21.8% and both thoracic and lumbar region in 16.7% of patients. Location of back pain was associated with location of major curve (Fig. 1, $P = 0.036$). In addition, low back pain was associated with higher AVR in the lumbar apex (low back pain = 11.83 ± 11.91 degrees, thoracic pain = 10.05 ± 10.07 degrees, $P = 0.02$) and lower lumbar lordosis (low back pain = 46.22 ± 15.04 degrees, thoracic pain = 58.15 ± 15.32 degrees, $P = 0.02$).

Bivariate comparisons between the pain versus no pain groups demonstrated no differences in demographics (Table 1). Figure 2 shows the scores of self-reported measures according to the groups. AIS patients with pain

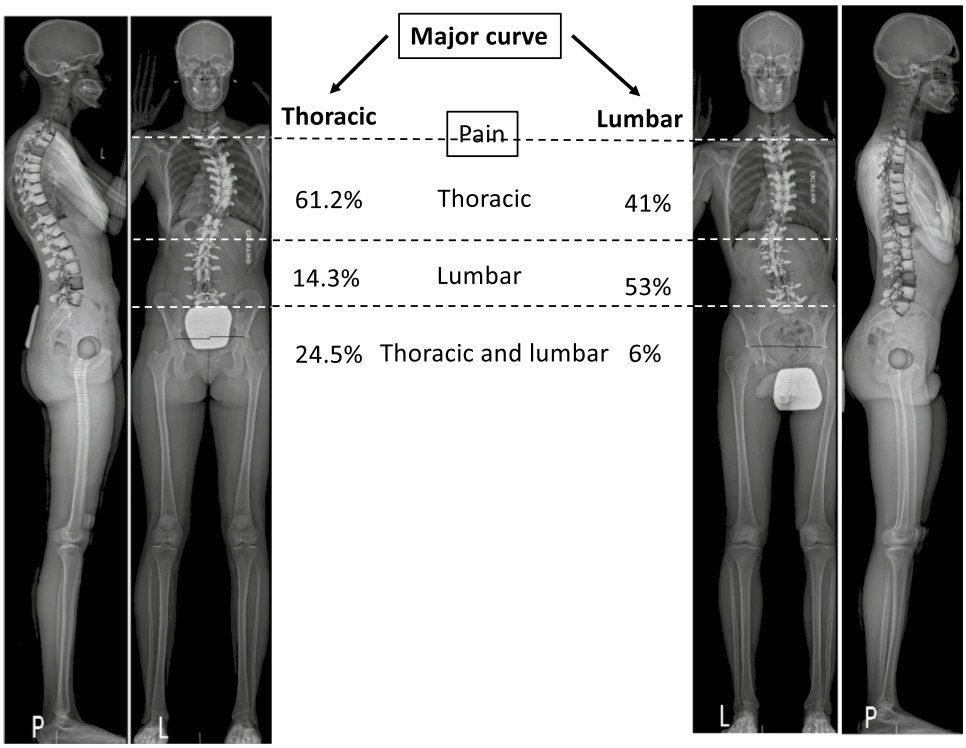

Fig. 1 Pain location according to the location of the major curve. *Note*: Chi-square = 6.668; $P = 0.036$

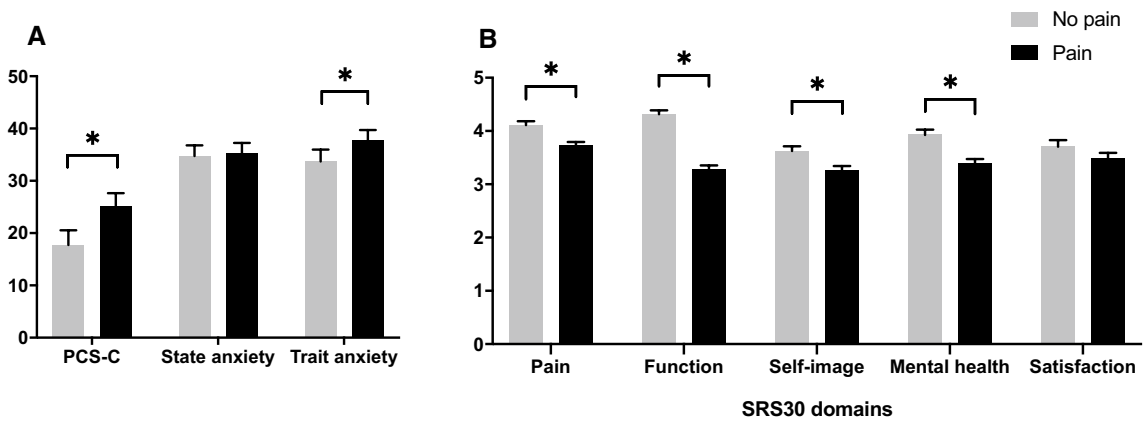

Fig. 2 Health-related quality of life measures in patients with and without back pain. *Note*: *Student *t* test, $P < 0.001$. PCS-C: pain catastrophizing scale for children. SRS30: Scoliosis Research Society 30. Error bars represent the standard error

presented greater scores in pain catastrophizing (mean difference = 7.36, CI95%: 3.61–11.12, $P < 0.0001$) and trait anxiety (mean difference = 4.04, CI95% 1.02–7.07, $P = 0.009$), and lower scores in level of function (mean difference = − 0.38, CI95% − 0.59–− 0.18, $P < 0.0001$), self-image perception (mean difference = − 0.35, CI95% − 0.58–− 0.12, $P = 0.003$), and self-reported state of mental health (mean difference = − 0.54, CI95% − 0.80–− 0.27, $P < 0.0001$). Bivariate analyses with biomechanical predictors of back pain are presented in Table 3. The initial model of multiple logistic regression contained the variables of body mass index, greatest Cobb angle, thoracolumbar Cobb angle, lumbar apical translation, AIR lower, thoracic kyphosis, pelvic asymmetry, PCS-C, trait anxiety, SRS30 self-image, and SRS30 mental-health. The final model of logistic regression is presented in Table 4. Independent risk factors for back pain in AIS were greater pain catastrophizing ($B = 0.061$, $P = 0.035$), poorer self-reported state of mental health ($B = -0.872$, $P = 0.023$), decreased thoracic kyphosis ($B = -0.033$, $P = 0.044$) and pelvic asymmetry ($B = 0.146$, $P = 0.047$).

Table 3 Bivariate analysis of radiographic factors associated with pain versus no pain groups. Data are presented as the Mean (± SD)

	Pain ($N=69$)	No Pain ($N=55$)	P values
Coronal plane			
Cobb proximal thoracic (°)	25.1 (± 10.1)	24.3 (± 11.8)	0.735*
Cobb main thoracic (°)	53.7 (± 15.2)	50.2 (± 13.0)	0.201*
Cobb thoracolumbar (°)	43.6 (± 16.4)	36.2 (± 14.2)	0.017*
Cobb major curve (°)	57.3 (± 12.8)	53.3 (± 10.5)	0.086*
Apical translation thoracic (mm)	38.1 (± 15.9)	34.4 (± 18.1)	0.237*
Apical translation lumbar (mm)	21.8 (± 19.2)	14.9 (± 16.3)	0.062**
Lateral pelvic tilt (°)	5.00 (± 3.44)	3.92 (± 3.36)	0.103*
Coronal balance (mm)	15.8 (± 12.3)	13.9 (± 9.91)	0.180*
Sagittal plane			
SVA (mm)	0.13 (± 23.6)	− 4.77 (± 21.1)	0.239*
T1-T12 kyphosis (°)	24.6 (± 18.7)	30.4 (± 14.0)	0.074*
L1-S1 lordosis (°)	58.5 (± 16.5)	57.1 (± 13.1)	0.619*
Pelvic incidence (°)	52.8 (± 14.0)	52.6 (± 12.7)	0.920*
Sacral slope (°)	44.8 (± 11.8)	45.1 (± 9.98)	0.902*
Pelvic tilt (°)	8.02 (± 8.06)	7.51 (± 8.46)	0.748*
Axial plane			
AVR apex major curve (°)	17.3 (± 9.80)	16.49 (± 9.90)	0.638*
AIR upper major curve (°)	22.0 (± 9.14)	21.5 (± 7.57)	0.777*
AIR lower major curve (°)	13.08 (± 6.84)	10.9 (± 5.02)	0.084*
AIR maximum (°)	11.9 (± 5.50)	13.2 (± 13.9)	0.964**
Torsion index (°)	35.5 (± 12.8)	33.6 (± 8.94)	0.376*

SD standard deviation, *SVA* sagittal vertical axis, *AVR* axial vertebral rotation, *AIR* axial intervertebral rotation

*Students *t* test and **Mann–Whitney test for group comparisons

Table 4 Multiple regression analysis with factors associated with back pain prevalence in AIS

	B	Adjusted-OR	95% CI	P values
T1-T12 kyphosis	− 0.033	0.968	0.937–0.999	0.044
Lateral pelvic tilt	0.146	1.157	1.002–1.336	0.047
Pain Catastrophizing Scale	0.061	1.063	1.004–1.126	0.035
SRS30–Mental health	− 0.872	0.418	0.197–0.885	0.023

Contribution of radiological and psychological factors to pain prevalence

Results of multivariate logistic regression models containing radiological variables from SterEOS 3D reconstructions demonstrated no discrimination ability of axial plane model (AUC: 0.56, $P=0.31$. Good discrimination was observed with the sagittal plane (AUC: 0.66, $P=0.004$) and coronal plane (AUC: 0.70, $P=0.002$) models. Slight improvement was obtained with a model containing coronal and sagittal plane variables (AUC: 0.75, $P<0.0001$). Overall, only a small improvement in model discrimination was obtained by adding axial plane variables (3 planes radiological model; AUC: 0.77, $P<0.0001$).

Morphological and psychological models' performances are demonstrated in Fig. 3. The morphological model's ability to discriminate the presence of pain calculated by AUC was 0.78 ($P<0.0001$) while the psychological presented an AUC of 0.74 ($P<0.0001$). Performance of combined morphological and psychological models improved significantly the model performance (AUC: 0.91, $P<0.0001$, Fig. 3).

Association between pain intensity, psychological and radiographic parameters

There was a significant association between self-reported pain intensity in the last 24 h and levels of catastrophizing (Fig. 4). High level of catastrophizing was correlated with high levels of worst pain ($r=0.413$, $P<0.0001$),

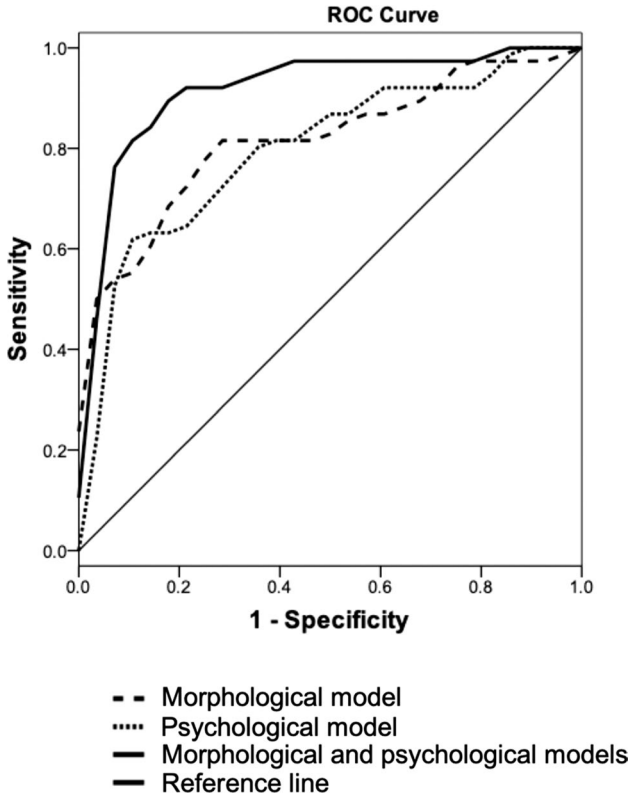

Fig. 3 Morphological and psychological models' performances to predict pain versus no pain in adolescent idiopathic scoliosis. *Note*: Morphological model: area under the curve (AUC) = 0.78, $P < 0.0001$; Psychological model: AUC = 0.74, $P < 0.0001$; morphological and psychological models: AUC = 0.91, $P < 0.0001$

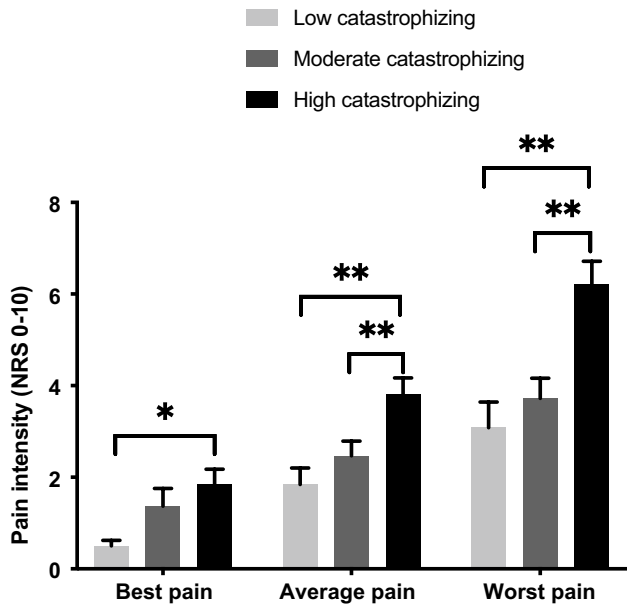

Fig. 4 Self-reported pain intensity according to levels of pain catastrophizing. *Note*: Student *t* test, *$P < 0.05$, **$P < 0.001$. Error bars represent the standard error

average pain ($r = 0.314$, $P = 0.001$), and best pain ($r = 0.214$, $P = 0.034$) experienced in the last 24 h. Greater level of catastrophizing was correlated with worse scores of pain ($r = -0.354$, $P < 0.0001$), function ($r = -0.407$, $P < 0.0001$), self-image ($r = -0.271$, $P = 0.006$), and mental health ($r = -0.439$, $P < 0.0001$) domains of SRS30. Trait anxiety was also correlated with pain intensity, function, self-image, and mental health (Table 5).

Association between radiographic parameters and pain intensity is demonstrated in Table 6. An interaction term between levels of pain catastrophizing and each one of radiographic variable was included in each linear regression model in order to evaluate the moderation effect of pain catastrophizing on the relationship between radiographic parameters and pain intensity. A statistically significant interaction PCS*Major Cobb angle ($P = 0.031$) and a main effect of Cobb angle ($P = 0.045$) on pain intensity were observed. A statistically significant interaction PCS*torsion index ($P = 0.016$) and a main effect of torsion ($P = 0.025$) on pain intensity were observed. In addition, a significant interaction between PCS*AIR upper major curve ($P = 0.021$) and main effect of AIR upper major curve ($P = 0.043$) were identified. The interactions between the radiographic variables and catastrophizing revealed that, in low catastrophizers, there is a significant association between greater spinal deformity (Cobb angle, torsion index, and AIR of the upper half of major curve) and higher pain levels (Fig. 5). For moderate and high catastrophizers, such positive correlation is absent.

Discussion

Despite being neglected for many years [2, 3], recent studies have highlighted that pain is an important issue in patients with AIS [1, 4, 37, 40]. Although the causal relationship is yet speculative given the cross-sectional designs, epidemiological studies have demonstrated that the prevalence of back pain is higher in AIS than in adolescents without scoliosis [41–43]. For example, in the study by Sato et al. [41], back pain in patients with AIS was reported as 27.5%, higher than adolescents without scoliosis (11.4%). Similarly, Kovacs et al. [43] observed an increased prevalence of back pain in schoolchildren reporting scoliosis (Odds-ratio = 2.87; CI95% 2.45–3.37). In a large database study with 1433 patients with AIS selected for surgery, Landman et al. [2] reported a prevalence of 73.6% of mild to severe back pain in the past month. Interestingly, mild to severe back pain was reported by 85.8% of patients in our study. To note, this study was designed specifically to evaluate pain in AIS, which could have contributed to this higher rate of pain complaint in our cohort.

There is growing evidence demonstrating that the spinal deformity is a pain generator in AIS. Recently, Bisson et al.

Table 5 Correlation matrix between self-reported questionnaires

	NRS of worst pain	NRS of average pain	NRS of best pain	PCS	State anxiety	Trait anxiety	SRS30–pain	SRS30 function	SRS30 self-image	SRS30 mental health
NRS worst pain	1									
NRS average pain	0.867**	1								
NRS best pain	0.480**	0.538**	1							
PCS-C	0.413**	0.314**	0.214*	1						
State anxiety	0.092	0.036	0.065	0.239*	1					
Trait anxiety	0.409**	0.391**	0.207*	0.486*	0.451**	1				
SRS30–pain	−0.580**	−0.538**	−0.265**	−0.354**	0.046	−0.172	1			
SRS30 function	−0.421**	−0.400**	−0.272**	−0.407**	−0.154	−0.400**	0.467**	1		
SRS30 self-image	−0.443**	−0.333**	−0.315**	−0.271**	−0.347**	−0.333**	0.345**	0.393**	1	
SRS30 mental health	−0.457**	−0.333**	−0.261**	−0.271**	−0.538**	−0.638**	0.418**	0.554**	0.554**	1

NRS numerical rating score, *PCS-C* pain catastrophizing scale-children, *SRS30* Scoliosis Research Society 30

*$P < 0.05$, **$P < 0.001$

Table 6 Linear regression between radiographic variables and back pain intensity

	Interaction term variable*PCS-C		Main effect	
	Beta	*P*	Beta	*P*
Coronal plane				
Cobb major curve	−1.042	0.031	0.411	0.045
Apical translation thoracic	−0.527	0.102	−0.077	0.939
Apical translation lumbar	−0.258	0.357	0.081	0.399
Lateral pelvic tilt	0.212	0.447	0.072	0.466
Coronal balance	0.193	0.503	0.108	0.258
Sagittal plane				
SVA	−0.173	0.390	0.130	0.167
T1-T12 kyphosis	0.329	0.187	0.080	0.416
L1-S1 lordosis	0.602	0.098	0.010	0.921
Pelvic incidence	0.186	0.630	0.050	0.611
Sacral slope	0.464	0.178	0.063	0.525
Pelvic tilt	−0.336	0.153	−0.004	0.967
Axial plane				
AVR apex major curve	−0.602	0.063	0.014	0.885
AIR upper major curve	−0.007	0.021	−0.134	0.043
AIR lower major curve	−0.006	0.096	0.033	0.330
Torsion index	−0.004	0.016	0.102	0.025

SVA sagittal vertical axis, *AVR* axial vertebral rotation, *AIR* axial intervertebral rotation

[10] identified advanced deterioration in young facet joint cartilage tissue in AIS patients, comparable with individuals with osteoarthritis. In another study looking at pain neurophysiology of patients with AIS and chronic pain, our group demonstrated that deformity severity is associated with impaired pain processing and modulation [1]. The results of the current study provided further evidence for an association between deformity and back pain. First, decreased thoracic kyphosis and pelvic asymmetry were identified, while controlling for psychological variables, as independent predictors for having moderate to severe back pain. Decreased thoracic kyphosis is part of the tridimensional aspect of the AIS, thus its severity generally reflects the overall deformity severity. Reduced thoracic kyphosis is a well-known painful compensatory mechanism for loss of lumbar lordosis in adult spinal deformity [44]. Despite recognized in adults, this was the first study to show the association between thoracic hypokyphosis and back pain prevalence in AIS. In fact, there is convincing evidence demonstrating that facet joint loading causes spinal cord hyperexcitability contributing to pain chronification [45].

Pelvic asymmetry is very common in AIS and it is associated with deformity severity [32]. Radiographic measures of pelvic asymmetry include the pelvic obliquity angle and the difference in heights of femoral heads, also known as

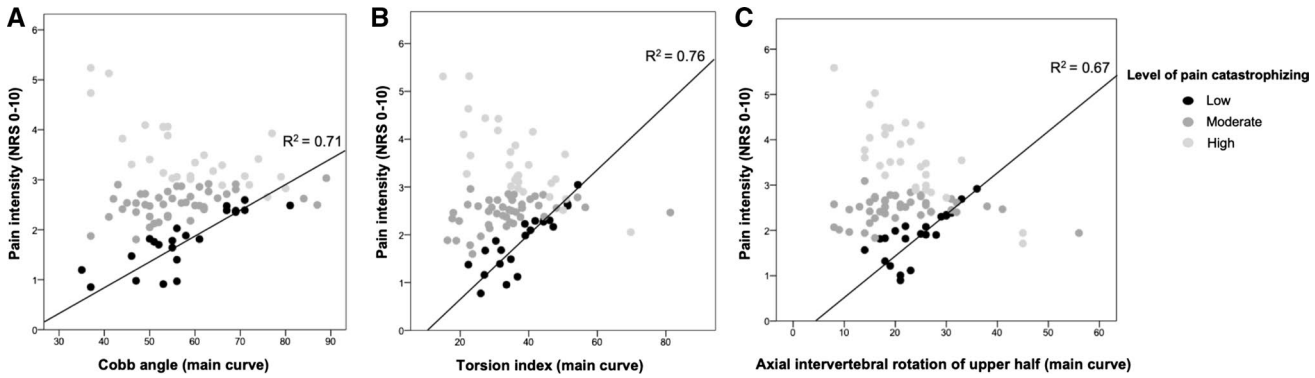

Fig. 5 Scatter plots representing the interaction between pain catastrophizing and severity of the spinal deformity on self-reported pain intensity (NRS 0–10)

functional LLD (leg length discrepancy) [32, 46]. In patients with AIS, LLD can be functional (resulting from altered mechanics), or structural (associated with bony shortening) [47]. Functional is much more common than structural LLD in the AIS population [32]. In fact, the relative spinopelvic alignment is suggested as a compensatory mechanism to maintain trunk equilibrium [48]. In this sense, extension and flexion of the lower limbs compensate the lumbar curve. Difference in height of femoral heads is a reliable measure easily obtained from the StereoEOS reconstructions which is highly correlated with the pelvic obliquity angle [32]. In patients with neuromuscular scoliosis, this pelvic asymmetry is commonly associated with hip contractures and it is recognized as a pain generator [49]. To the best of our knowledge, this was the first study to identify an association between pelvic asymmetry (i.e., functional LLD) and back pain in AIS. The relationship between pelvic asymmetry and chronic back pain in the general population has been investigated [50–53]. In patients with AIS, pelvic asymmetry is known to be associated with unequal weight distribution, muscular imbalance of the trunk, and decreased postural stability, which may predispose patients to back pain [54–56]. In addition, pelvic asymmetry seems to alter the patterns of trunk movement and mechanics of the spine [51]. Our results suggest further exploration of pelvic measurements and LLD as a cause of back pain in AIS. Despite recognizing the exploratory nature of this study and the need for further validation of these findings, the identification of thoracic hypokyphosis and pelvic asymmetry as independent predictors for back pain highly suggests that the deformity itself has influence on back pain prevalence in this population. Furthermore, besides confirming the association between curve type and pain location [37], we observed that patients with pain located at the lower back region have greater axial rotation of the apical lumbar vertebrae.

Besides endorsing the link between morphology and pain, our results highlight the importance of investigating psychological aspects when evaluating chronic pain in AIS. For example, the regression model containing radiographic and psychological variables presented increased discrimination power in comparison with the model containing only radiological variables. In addition, pain catastrophizing was identified as a strong predictor for self-reported pain prevalence and intensity. In fact, pain catastrophizing is an important psychological construct in pediatric pain assessment [1, 27]. Despite being reported in other painful conditions [16–21], this was the first study to confirm this association in AIS. Our results show that pain catastrophizing moderates the association between deformity severity and pain intensity. Interestingly, the positive correlation between deformity severity and pain intensity was only seen in patients with low level of catastrophizing in our data. We recognize that further larger studies should better explore this topic, but our data suggest that the role of morphology for back pain in AIS is more evident in low catastrophizers. In other words, for moderate or higher catastrophizers, the deformity may not play a significant role for self-reported pain intensity. In light of the current biopsychosocial model of pain assessment [57], our study strikes the need for further exploration of psychosocial issues involved in AIS-related back pain. As the role of parental catastrophizing in children pain behavior is well-established [58, 59], this variable should be further explored in AIS-related pain.

Better characterization of pain mechanisms can potentially improve pain management [1, 60]. Even though pain research continues to advance, relatively little attention has been given to patients with AIS. For example, studies investigating the effect of bracing on back pain in AIS are usually retrospective and provide conflicting results [37, 61–64]. One might argue that a subset of patients have a higher component of mechanical pain that would benefit from bracing or even from more invasive procedures. On the other hand, certain psychological factors may predispose patients to pain chronification [65] despite the deformity management. In

the same way, as adolescents are known to have different pain coping profiles [66, 67], the impact of different coping strategies should be explored in future studies. In summary, larger studies could better identify clusters of patients more likely to have pain driven by deformity or psychosocial components.

Using a standard 3D reconstruction technique [35] this was the first study to investigate the relationship between axial vertebral rotations and pain in this population. Results showed a main effect of torsion of the main curve and AIR of the upper half of the curve on self-reported pain intensity. In addition, higher axial vertebral rotation of the apical lumbar vertebra was associated with pain in the lower back. However, variables obtained with the axial plane reconstructions were not independent predictors of back pain and the model containing only axial plane variables had no discrimination for painful scoliosis. These results suggest that the axial rotation may have a lower effect on pain generation in comparison to coronal or sagittal loading. Another possible explanation is that, despite being the most accurate method, the average 2.4° measurement error [35] with sterEOS 3D reconstruction could impact the results. The reliability of EOS has been investigated by several authors [68–71].

This study presents several limitations that should be considered. First, as the study was designed specifically to assess pain in patients undergoing surgery and that pain is not considered an indication for surgery in AIS, it is possible that there was a bias towards patients with pain and their likelihood to participate in the study. As previously mentioned, we observed a high prevalence of self-reported pain. Moreover, the mean reported pain intensity in our study was 2.66 (±2.18), slightly higher than the study by Théroux et al. [37] (1.63 ± 1.89). Second, in order to identify predictors for painful versus non-painful scoliosis, we used the same arbitrary criteria adopted by Djurasovic et al. [38]: no or mild pain representing the non-painful group versus moderate to severe pain representing the painful group. As pain is a subjective experience, future studies with larger sample sizes should further validate our findings including patients with mild pain. Third, these results may not be applicable for patients with mild scoliosis (i.e., Cobb angle from 10 to 25 degrees), frequently seen in spine clinics. Fourth, no positive psychological factors were assessed in this study (e.g., pain acceptance, self-efficacy, social supports). Fifth, one should recognize that there are multiple reasons for having catastrophizing thoughts about pain in this population that should be explored in further studies (e.g., knowledge of scoliosis, knowledge of pain pathways, untreated anxiety, etc.). It is important to highlight that pain catastrophizing is defined as a negative orientation or mental set about actual or anticipated pain [15]. This trait-based concept is assessed in PCS as the tendency toward engaging in magnification, rumination, and helplessness "when in pain", with participants asked to reflect on an unspecified painful experience. The questionnaire, thus, evaluate pain catastrophizing as a trait, that is, a stable tendency or predisposition to catastrophize. The item content of the PCS magnification and rumination scales taps both cognitive content (i.e., what people think) as well as cognitive process (i.e., how people think), while the helplessness scale taps both of these coping domains as well as emotional coping. It was reported that scores on the PCS remain stable across time and that the PCS is appropriate for measuring trait pain catastrophizing in both clinical pain and nonclinical populations [15]. PCS scores have been found to correlate with measures of other stable traits, including personality traits [72]. This data support the validity of the trait-based conceptualization of catastrophizing of PCS, the major psychological instrument used in our study. Finally, similarly to the previous studies in the field, the cross-sectional design precludes absolute conclusions on the causality of radiographic factors and back pain prevalence and intensity.

Conclusions

Despite the limitations, this exploratory study demonstrated that morphological and psychological factors are related to pain in AIS. Pain is associated with worse quality of life measures. Moreover, pain catastrophizing is an important construct in AIS-related pain and should be taken into consideration when evaluating these patients.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflicts of interest related to this work.

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