Exploring Correlations Between Pain and Deformity in Idiopathic Scoliosis With Validated Self-reported Pain Scores, Radiographic Measurements, and Trunk Surface Topographic Measurements

Peter M. Cirrincione, BA, Ankush Thakur, MS,* Colson P. Zucker, BA,* Jenna L. Wisch, BS,* Benjamin N. Groisser, PhD,* Joseph Nguyen, MPH,* Douglas N. Mintz, MD,* Matthew E. Cunningham, MD, PhD,* M. Timothy Hresko, MD,† Ram Haddas, PhD,‡ Howard J. Hillstrom, PhD,* Roger F. Widmann, MD,* and Jessica H. Heyer, MD**

Background: Up to 75% of patients with idiopathic scoliosis (IS) report back pain, but the exact contributors are unclear. This study seeks to assess how pain correlates with demographics, radiographic and surface topographic (ST) measurements, and patient-reported outcome measures (PROMs) in patients with IS.

Methods: Patient-Reported Outcome Measurement Information System (PROMIS) Pain Interference (PI) and Scoliosis Research Society revised (SRS-22r) pain domain from an IRB approved prospectively collected registry containing patients 11 to 21 years old with IS were correlated (Spearman coefficients) with measurements from whole-body EOS radiography and ST scanning, PROMIS 1.0 PROMs, Trunk Appearance Perception Scale (TAPS), and SRS-22r domains. SRS-22r and PROMIS-PI were also compared between different sex, scoliosis severities, and primary curve locations with Mann-Whitney U or Kruskal-Wallis tests, and if significant differences were found, included with the 5 highest univariate correlated variables into stepwise multivariate linear regression models ($P<0.05$ to enter, $P>0.1$ to remove) predicting SRS-22r pain and PROMIS-PI.

Results: One hundred and forty-nine patients (14.5 ± 2.0 y, body mass index 20.6 ± 4.1 kg/m^2, 96 (64%) female, mean major coronal curve 40 ± 19 deg, range: 10 deg, 83 deg) reported mean PROMIS-PI of 42.2 ± 10.0 and SRS-22r pain of 4.4 ± 0.6. SRS-22r self-image was the most correlated variable with both SRS-22r pain (rho = 0.519) and PROMIS-PI (rho = −0.594). Five variables, none of which were ST or radiographic measures, strongly predicted SRS pain domain ($R=0.711$, $R2=0.505$, $N=138$). Two variables (SRS-22r self-image and SRS-22r function) were utilized by a model correlated with PROMIS-PI ($R=0.687$, $R2=0.463$, $N=124$).

Conclusions: SRS-22r function and self-image domains were more strongly correlated with SRS-22r pain and PROMIS-PI than any radiographic or ST measurements.

Level of Evidence: Level II—retrospective study.

Key Words: scoliosis, idiopathic scoliosis, pain, Surface Topography, PROMIS, SRS

(*J Pediatr Orthop* 2023;43:608–614)

From the *Hospital for Special Surgery, New York, NY; †Boston Children's Hospital, Boston, MA; and ‡University of Rochester Medical Center, Rochester, NY.

The registry collecting this data was approved by an IRB and the analysis plan for this project was approved by the registry's steering committee.

De-identified data are available upon request.

Funding support for this project was provided by the Leon Root Chair in Pediatric Orthopaedic Surgery at the Hospital for Special Surgery (HSS), the Hospital for Special Surgery Lerner's Children's Pavilion Research Fund, the Foundation Yves Cotrel Basic Science Research Grant, the Neumann Family Fund Foundation, and the Professor Rahamimoff Travel Grant for Young Scientists of the US-Israel Binational Science Foundation. Physical space was provided by the HSS Department of Radiology, and construction costs were supported by HSS.

The authors have received benefits for personal or professional use from a commercial party related directly or indirectly to the subject of this manuscript. Benefits have been directed to a research fund, with which the authors are associated. A grant and philanthropic support have been received to perform this work. The authors may receive benefits for personal or professional use from a commercial party related directly or indirectly to the subject of this manuscript because there are 2 patents pending, although no financial renumeration to date.

Reprints: Jessica H. Heyer, MD, Hospital for Special Surgery, 535 E. 70th St., New York, NY 10021. E-mail: heyerj@hss.edu.

DOI: 10.1097/BPO.0000000000002493

Twenty-three to seventy-five percent of patients with idiopathic scoliosis (IS) report back pain; however, the cause remains unknown.[1–4] In this population, biopsychosocial factors such as depression and sex have been correlated with the presence and severity of back pain.[5] Furthermore, preoperative pain, self-image, and mental health are associated with pain improvement after surgery.[6–8]

The correlation between biopsychosocial factors, self-image, and pain in IS begs the question of whether there is an objective aspect of physical deformity that is linked to pain or if the correlation is more reliant on a patient's perception of his or her image. Surface topography (ST) has demonstrated reliability for assessing deformity, symmetry, and range of motion for IS,[9–11] and may be useful in objectively assessing a patient's deformity and its association with pain. A previous study identified that Scoliosis Research Society (SRS)-22r mental health and self-image domains correlate poorly with surface topographical measures of deformity;[12] however, the pain domain was not assessed.

Therefore, this study aims to compare the correlation of demographic factors, surface topographic measurements, radiographic measurements, and patient-reported outcome measures (PROMs) of self-image, mental health, global health, satisfaction with management, and function with patient-reported pain and pain interference. The hypothesis is asymmetry as measured by surface topography will correlate strongly with pain in pediatric patients.

METHODS

Patients aged 11 to 21 with IS were eligible for prospective enrollment in a single-center IRB-approved registry if they provided informed consent and had no prior history of spinal surgery. From this database, 149 patients aged 11 to 19 were included. All patients underwent surface topographic scanning and standard-of-care whole-body EOS radiography. They completed PROMs including Trunk Appearance Perception Scale (TAPS), SRS-22r, and Patient-Reported Outcome Measurement Information System (PROMIS) 1.0. Self-reported pain was assessed using SRS-22r pain and PROMIS Pain Interference (PI).

Radiographic parameters were obtained from EOS imaging of the entire skeleton and EOS reconstructions. Surface topographic imaging data was obtained using the 3dMD body system (3dMD Atlanta, GA), and measurements were computed using an automated analysis pipeline as described by Groisser et al.[11]

On the basis of Groisser's findings, only highly reliable ST measures obtained in the standing EOS Pose (intraclass correlation coefficient >0.7) were included:[11] maximum back surface rotation (Fig. 1A), back area asymmetry, C7 angle, torso volume asymmetry (Fig. 2), anteroposterior centroid displacement (Fig. 1B), principal axis maximum (Fig. 1C), shoulder volume asymmetry, centroid lateral displacement (Fig. 1B); range of motion (ROM) measures were also included:[10] coronal angle ROM, forward sagittal angle, C7 twisting ROM, C7 twisting asymmetry index (Fig. 3).

Radiographic measurements of interest included major coronal curve measured with the Cobb technique, pelvic incidence, pelvic obliquity, maximum axial vertebral rotation, maximum thoracic kyphosis, maximum lumbar lordosis, sagittal vertical axis, distance from the central acoustic meatus (CAM) plumb line to a plumb line at the femoral head center on sagittal view (CAM Plumb Line), distance from a plumb line at the center of C7 to the center sacral line (CSL) on coronal view (Coronal C7-CSL), and the difference between pelvic incidence and lumbar lordosis.

All data were analyzed using SPSS version 22.0 (IBM Corp., Armonk, NY). Normal distribution for the SRS-22r pain and PROMIS-PI was assessed with Kolmogorov-Smirnov tests. SRS-22r pain and PROMIS-PI were compared with Mann-Whitney U tests between primary curve location (thoracic vs. lumbar) and sex. A Kruskal-Wallis test was used to compare SRS-22r pain domain and PROMIS-PI between groups with different severity of scoliosis (mild: 10 deg $\leq$ major coronal curve $<$ 25 deg; moderate: 25 deg $\leq$ major coronal curve $\leq$ 45 deg; severe: major coronal curve $>$ 45 deg).

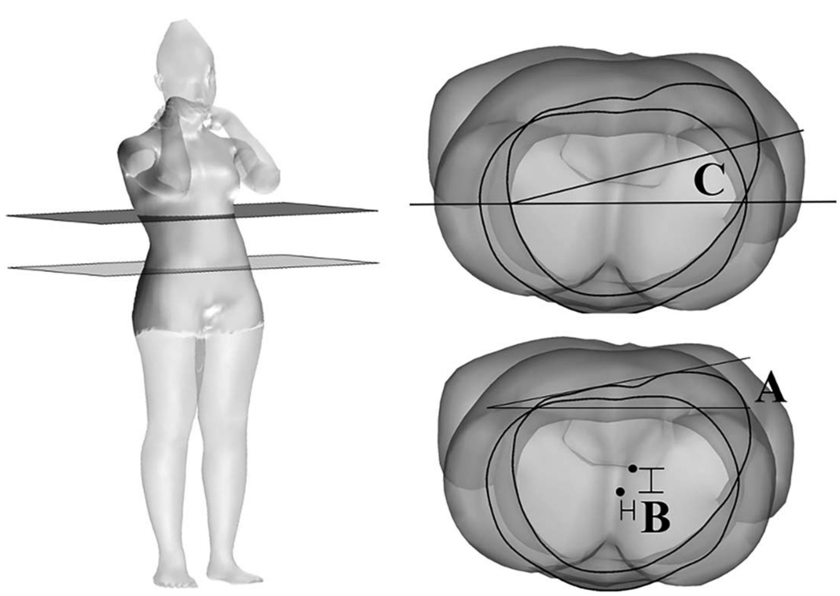

Figure 1. Two axial slices of the trunk demonstrating 3 surface topography measurements: (A) back surface rotation, (B) anteroposterior and lateral centroid displacements, (C) principal Axis Maximum.

Figure 2. Torso mesh representation of the volume utilized in the torso volume asymmetry measurement.

Univariate analysis was utilized to correlate PROMs, age, body mass index (BMI), ST measurements, and radiographic measurements to SRS-22r pain and PROMIS-PI scores and Spearman coefficients are reported. Five continuous variables with the highest univariate correlations and categorical variables with significantly different PROMIS-PI or SRS-22r pain were included in multi-step linear regression models to predict pain and PROMIS-PI using stepwise variable inclusion $P<0.05$ to enter, $P>0.1$ to remove.

RESULTS

One hundred and forty-nine patients with IS were included in the analysis; mean age was 14.5 ± 2.0 years and 96 (64%) of patients were female (Table 1). Curve size was categorized as severe in 64 (43%) of patients, and moderate in 41 (28%), with an average major curve size of 40 ± 19 degrees.

Table 1. Patient Demographics

Characteristic	Patients, n = 149
Age, mean ± SD	14.5 ± 2.0 years
Sex	
Female	64%
Male	36%
BMI, mean ± SD	20.6 ± 4.1 kg/m^2
Curve location	
Thoracic	68%
Lumbar	32%
Severity	
Mild	30%
Moderate	28%
Severe	43%
Major coronal curve	
Mean ± SD	40 ± 19 deg
Range (minimum, maximum)	(10 deg, 83 deg)

BMI indicates body mass index.

One hundred and forty-nine patients (100%) completed the PROMIS-PI questionnaire, whereas 142 patients (95%) completed the SRS-22r questionnaire. The mean PROMIS-PI was 42.2 ± 10.0 and SRS-22r pain was 4.4 ± 0.6. Females had worse SRS-22r pain scores than males, but there was no difference in PROMIS-PI scores. No difference was found between curve location and SRS-22r pain or PROMIS-PI. SRS-22r pain and PROMIS-PI differed significantly between mild, moderate, and severe scoliosis; patients reported poorer SRS-22r pain and PROMIS-PI scores in the severe scoliosis group (Table 2).

The univariate correlations of SRS-22r pain and PROMIS-PI to other PROMs, demographic variables, surface topographic variables and radiographic parameters are noted in Table 3. For both PROMIS-PI and SRS-22r pain, the highest correlation was of moderate strength, with SRS-22r self-image. For PROMIS-PI, SRS-22r function and SRS-22r mental health followed as the next most correlated variables. For SRS-22r pain, SRS-22r function and SRS-22r management were the next most correlated variables. BMI was found to be significantly, albeit weakly, correlated with

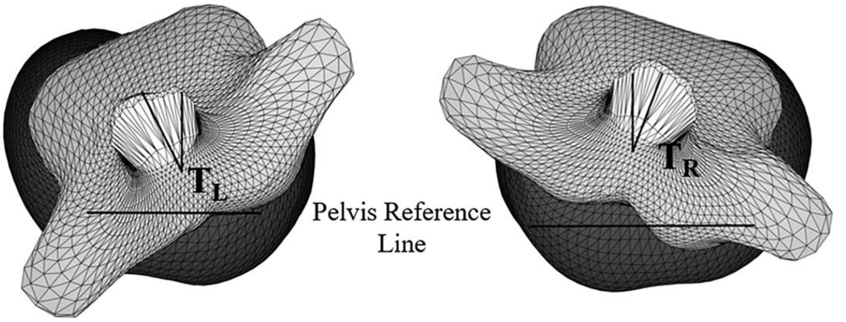

Figure 3. Axial views demonstrating measurements utilized to calculate C7 twisting asymmetry index (ASI). Twisting ASI = 2 × (T_R–T_L)/(T_R+T_L) × 100.

Table 2. PROMIS-PI and SRS-22r Pain Scores for Various Patient Groups

Characteristic	PROMIS-PI mean ± SD (N = 149)	*P*	SRS-22r mean ± SD (N = 142)	*P*
All patients	42.2 ± 10.0	N/A	4.4 ± 0.6	N/A
Sex		0.137		0.007*
Female	43.2 ± 10.4		4.3 ± 0.6	
Male	40.4 ± 9.2		4.6 ± 0.5	
Primary curve location		0.309		0.079
Thoracic	42.9 ± 10.5		4.3 ± 0.6	
Lumbar	40.8 ± 8.9		4.5 ± 0.5	
Severity		0.001*		0.004*
Mild (10 deg < MCC < 25 deg)	38.1 ± 9.0		4.6 ± 0.5	
Moderate (25 deg ≤ MCC ≤ 45 deg)	42.2 ± 11.1		4.4 ± 0.7	
Severe (MCC > 45 deg)	44.9 ± 9.2		4.2 ± 0.6	

Higher PROMIS Pain Interference scores indicate worse pain, whereas lower SRS22 scores indicate more pain.

MCC indicates major coronal curve; N/A, not applicable; PROMIS-PI, Patient-reported Outcome Measurement Information System Pain Interference; SRS, Scoliosis Research Society.

both pain scores. Of the surface topographic variables, maximum anteroposterior centroid displacement (Fig. 1B) was significantly correlated to both pain scores, but the correlations were weak. The only other surface topographic variable that was found to be significant at the $P < 0.01$ level was principal axis maximum (Fig. 1C) for PROMIS-PI. No range of motion measurement was correlated with either pain score. Of the radiographic measurements, major coronal curve was found to be significantly correlated, albeit weakly with pain. Maximum axial vertebral rotation was only significant at the $P < 0.01$ level for PROMIS-PI, and at the $P < 0.05$ level for SRS-22r pain (Table 3).

A multivariate stepwise model was created including the 5 highest univariate correlated continuous variables (Table 3, bold) and categorical variables (sex and scoliosis severity) with SRS-22r pain. Only 5 variables (SRS-22r self-image, BMI, SRS-22r function, SRS-22r management, sex) of the potential 8 were used to generate a model with the strongest possible correlation with SRS-22r pain ($r = 0.711$, $r^2 = 0.505$, N = 138).

A multivariate stepwise model was created including the 5 highest univariate correlated continuous variables (Table 3, bold) and 1 categorical variable (scoliosis severity) with PROMIS-PI. Only 2 variables (SRS-22r self-image and SRS-22r function) of the potential 8 were used to generate a model with the strongest possible correlation with PROMIS-PI ($r = 0.687$, $r^2 = 0.463$, N = 124).

DISCUSSION

Psychological factors may contribute to orthopaedic pain,[13] and for individuals with scoliosis improvements in pain have been correlated with improved patient-reported self-image.[4] Some findings, however, challenge the suggestion of a psychological etiology for back pain in IS. For example, compared with individuals affected by nonspecific low back pain without scoliosis, scoliosis patients report pain localized to specific regions and in a smaller area.[14,15] Other studies have correlated self-reported pain to self-image; however, this study is significant in being the first to correlate self-reported pain with surface topography data, an objective measure of self-image. This study sought to assess for significant correlations between radiographic/surface topographic measurements of deformity and validated pain PROMs. Although we found weak correlations with SRS-22r pain or PROMIS-PI, the pain scores were much more highly correlated with other PROM subsections than with deformity severity.

The population studied did not report a severe burden of pain. The median SRS22 pain, 4.6 is near the minimum pain score (5.0) and the median PROMIS-PI, 42.2, is within one standard deviation of the general population mean (50 ± 10). However, differences among populations were seen in the study. In univariate analysis, females reported worse pain on SRS-22r but not on PROMIS-PI. This could be due to the mild nature of the reported pain, which may not interfere with the daily lives of otherwise healthy adolescents, and therefore although pain is different between groups pain interference is not different. Differences between sexes have also been found in other studies, with males having higher preoperative self-image, less postoperative pain, and better mental health,[16–20] although these findings are not reproduced in all populations.[21]

Several ST and radiographic measurements demonstrated weak correlations with SRS-22r pain and PROMIS-PI. In the coronal plane, C7 angle and maximum curve angle magnitude were weakly correlated. Previous studies report the magnitude of curve does not correlate linearly with pain,[22,23] and that even patients with small curves describe more pain and days off school compared with controls.[24] The surface topographic measurements with the highest univariate correlations with SRS-22r pain and PROMIS-PI measures were (1) rotational (principal axis maximum, Fig. 1C), and (2) sagittal (maximum AP centroid displacement, Fig. 1B) plane deformity. Interestingly, no similar correlation was established between radiographic measures of sagittal imbalance and pain. A radiographic measure of rotational deformity, maximum axial vertebrae rotation, was also correlated with SRS-22r pain and PROMIS-PI and therefore whether measured radiographically or with surface topography, rotational deformities weakly correlated with pain in univariate analysis. Regardless of the univariate correlations, no surface topographic or

Table 3. Univariate Correlations With SRS-22R Pain and PROMIS Pain Interference

	Pose	Variable	PROMIS-PI rho value (N = 149)	SRS-22R pain domain rho value (N = 142)
Descriptive	N/A	Age	0.104	−0.050
		BMI	0.327†‡	**−0.353**†¶¶
PROMs	N/A	TAPS	**−0.372**†§	0.290†##
		SRS-22R function domain	**−0.501**†‖	**0.403**†‖
		SRS-22R management domain	−0.275†‖	**0.402**†‖
		SRS-22R mental health domain	**−0.412**†‖	**0.317**†‖
		SRS-22R self-image domain	**−0.594**†‖	**0.519**†‖
		PROMIS global health	**−0.309**†§	0.255†***
Surface topography	EOS pose¶	Maximum AP centroid displacement	0.240†¶	−0.297†¶
		Maximum lateral centroid displacement	0.152¶	−0.122¶
		BSR maximum	0.144¶	−0.056¶
		Principal axis maximum	0.251†¶	−0.155
		Back area asymmetry	0.138¶	−0.092¶
		C7 angle	0.165	−0.096¶
		Torso volume asymmetry	−0.001¶	0.057¶
		Shoulder volume asymmetry	0.166	−0.093¶
	ROM	Forward sagittal angle normalized	−0.122#	−0.017‡¶
		Coronal angle ROM	0.047**	−0.065‡‡‡
		C7 twisting ROM	−0.102††	0.020§§§
		C7 twisting ASI	−0.116††	0.011§§§
Radiographic measurements		Major coronal curve	0.275†	−0.264†‖
		Maximum kyphosis	−0.078‡‡	0.125§
		Maximum lordosis	0.069§§	−0.065¶¶
		Maximum axial vertebra rotation	0.302†	−0.206
		SVA	−0.023§§	0.075¶¶
		CAM plumb line (sagittal)	−0.073§	0.080##
		Coronal C7-CSL	0.167	−0.145‖‖‖
		Pelvic incidence	0.144	−0.049‖
		Pelvic incidence—lumbar lordosis (difference)	0.045	−0.002‖
		Pelvic obliquity	0.134##	−0.128‖

Highest 5 univariate correlated variables for each pain score are bold.
Number of correlations the same as the number of responses for each pain PROM unless specified.
*Correlation is significant at the 0.05 level.
†Correlation is significant at the 0.01 level.
‡N = 145.
§N = 139.
‖N = 142.
¶PROMIS-PI N = 144, SRS-22R Pain N = 137.
#N = 104.
**N = 117.
††N = 129.
‡‡N = 146.
§§N = 144.
‖‖N = 147.
¶¶N = 138.
##N = 134.
***N = 132.
†††N = 101.
‡‡‡N = 113.
§§§N = 124.
‖‖‖N = 136.
AP indicates anteroposterior; ASI, asymmetry index; BMI, body mass index; BSR, body surface rotation; C7, cervical vertebra 7; CAM, central acoustic meatus; CSL, central sacral line; N/A, not applicable; PI, pain interference; PROM, patient-reported outcome measure; PROMIS-PI, Patient-reported Outcome Measurement Information System Pain Incidence; ROM, range of motion; SRS, Scoliosis Research Society; SVA, sagittal vertical axis; TAPS, trunk appearance perception scale.

radiographic measures contributed to multivariate models for either SRS-22r pain or PROMIS-PI.

In an optimized multivariate model, the model removed radiographic and surface topographic variables in favor of 2 variables (1. SRS-22r Self-Image; 2. SRS-22r Function) which together were strongly correlated with PROMIS-PI. Similarly, in an optimized multivariate model assessing correlation with PROMIS-PI, the model removed radiographic and surface topographic variables in favor of 5 other variables (SRS-22r self-image, BMI, SRS-22r function, SRS-22r management, sex), which together strongly correlated with SRS-22r pain.

Patient-reported outcomes, specifically SRS-22r self-image, function, and management domains, correlate more strongly with pain PROMs than any surface topographic or radiographic measurements. These findings suggest that magnitude of scoliotic curve and magnitude of truncal asymmetry may contribute less to self-perceived pain than does patient self-image. A study previously correlated radiographic and physical examination measures of spine deformity with PROM's, finding both were significantly correlated with pain and self-image.[19] However, previous studies with surface topography have produced mixed results. One study on 45 preoperative patients found radiographic measures correlated more strongly with quality of life than surface topographic measures.[25] Another found self-image, but not pain, was correlated with surface topography.[26] A prior longitudinal study on pain trajectories after spinal fusion for adolescent IS (AIS) found self-image scores at baseline were different for those grouped into "delayed pain," "pain improvement," and "no pain" throughout recovery from posterior spinal fusion for AIS.[8] Another prospective survey of 87 patients up to 5 years postoperatively found self-image and pain improved by at least the minimum clinically important difference at 1 year postoperatively, but only pain remained elevated at final follow-up.[27]

Limitations in our study include the lack of a control group with which to compare the IS patients. The prospectively collected registry data utilized in this study does include a control population, but those patients are collected from the sports medicine department. As such, the control patients often present for evaluation for a musculoskeletal pain complaint, rendering them a poor control population for the purpose of this study. In addition, there is a disproportionate number of males in the study. This skew may be due to males being willing to participate in the surface topographic protocol and body scanning. This study does not apply to the adult population. Although this study did not support our hypothesis that asymmetry as measured by surface topography would correlate strongly with pain in patients with IS, the potential for strong relationships between ST and PROMs within the population of adults with long-term degenerative changes remains unexplored. Previous research has not found a correlation between radiographic parameters and patient-reported pain, but ST has yet to be studied in the adult spinal deformity population.[28,29] In addition, relationships among different planes of deformity may lead to spurious correlations. For example, rotational deformity can increase with an increasing major coronal curve so the weak correlation between pain and rotational measures may be explained by the correlation between major coronal curve and pain. However, the relationships between deformity parameters are not the focus of this work, which instead demonstrated that no surface topographic or radiographic measurements of deformity correlated with pain and other self-reported PROMs. Limitations also include the specific questions asked by the SRS-22r pain and the PROMIS-PI; the PROMIS questionnaire is limited to the last 7 days, made specifically for the pediatric population, and does not ask about the presence or severity of pain. Instead, it asks about the impact of pain on emotions, sleeping, schoolwork, attention, and physical activity. The SRS-22r pain is a more globally applicable questionnaire but focuses on the amount and severity of pain in the past 6 months. However, the strength of these 2 questionnaires is that they have both been validated for the AIS population and assess slightly different qualities-pain versus the impact of pain on daily life.[30,31] This study also does not include patient race, which has been known to impact SRS-22r pain scores.[28,29,32]

CONCLUSION

In individuals with IS, pain is more strongly correlated with other patient-reported outcomes such as SRS-22r function, self-image, and management than radiographic or ST measurements. Although some radiographic and surface topographic measures significantly correlated with pain and pain interference, the correlation was weak and the variables were not included in strongly correlated multivariate models. Future research should assess whether management directed towards optimizing other self-reported PROM's, such as self-image and physical function, impacts self-reported pain.

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