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RESEARCH

Responsiveness and minimal clinically important changes of surface topography parameters in adolescents with idiopathic scoliosis: results from the schroth exercise trial

Nada Mohamed[1] · José María González Ruiz[1,2] · Sanja Schreiber[3] · Eric Parent[3] · Qipei Mei[4] · Lindsey Westover[1]

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Abstract

Introduction Adolescent idiopathic scoliosis (AIS) affects 2–3% of adolescents, causing spinal curvature and functional limitations. Traditional assessment using the Cobb angle may only partially capture patient concerns about aesthetics. The Schroth scoliosis-specific exercises (SSE), focusing on posture correction, have shown promise for reducing the Cobb angle and preventing progression, though research on its cosmetic impact is limited. Surface topography (ST) offers a radiation-free alternative to assess AIS, but determining what is a meaningful change for patients remains underexplored. The objective of this study is to determine the Minimal Clinically Important Changes (MCIC) in ST parameters in AIS after undergoing 6 months of Schroth SSE exercises.

Methods This is a secondary analysis from a randomized controlled trial. Participants ($n = 124$) were recruited from a Scoliosis Clinic and randomized into standard care (observation or bracing) and Schroth intervention added to standard care groups (one-hour weekly supervised session, 30–40 min daily home exercises). A global Rating of Change (GRC) was self-reported after six months, and asymmetry parameters of root mean square (RMS) and maximum deviation (MaxDev) over the asymmetry patch corresponding to the spinal curve were obtained through surface torso scans captured at baseline and six months. Pearson correlation and receiver-operating characteristic (ROC) curve analysis were performed to determine the MCICs. Subgroup analyses were also conducted to ascertain MCICs for thoracic and lumbar curve types.

Results GRC ratings correlated with changes in RMS (r=-0.510, $p < 0.001$) and MaxDev (r=-0.409, $p < 0.001$). Participants who reported improved (GRC$\geq$2) posture saw a 1.76 ± 2.9 mm and 3.29 ± 6.5 mm decrease in RMS and MaxDev, respectively. In contrast, RMS and MaxDev increased by 1.03 ± 3.0 mm and 1.26 ± 5.6 mm, respectively, among individuals who stated that their posture had deteriorated or not changed (GRC < 2). Using ROC analysis, MCICs for RMS and MaxDev were determined to be -0.27 mm (area under the curve (AUC) 0.746, sensitivity 67%, specificity 74%) and −0.49 mm (AUC 0.717, sensitivity 64%, specificity 68%), respectively, for overall improvement perception. Having met both thresholds reduced sensitivity to 62% and achieved 74% specificity. MCICs for thoracic curve types were −0.58 mm (AUC 0.618, sensitivity 60%, specificity 53%) for RMS and −1.32 mm (AUC 0.632, sensitivity 73%, specificity 92%) for MaxDev. MCICs for lumbar curve types were −0.26 mm for RMS (AUC 0.881, sensitivity 73%, specificity 92%) and −0.61 mm for MaxDev (AUC 0.811, sensitivity 68%, specificity 83%).

Conclusion Changes in RMS and MaxDev were aligned to GRC score reflecting perceived improvements in back condition. Stronger associations were observed between ST parameters and perceived improvement in lumbar than thoracic or combining all curves.

Keywords Adolescent idiopathic scoliosis · Surface topography · Schroth exercises · Postural asymmetry · Patient-reported outcome measures

Extended author information available on the last page of the article

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Introduction

Adolescent idiopathic scoliosis (AIS) is a paediatric condition affecting up to 5% of the population, with a higher prevalence in females [1, 2]. The scoliotic spine exhibits a three-dimensional lateral deviation, rotation, and extension [3]. Children with AIS can experience breathing difficulties, back pain, limited physical function, and poor self-image [4–9]. The Cobb angle is the gold standard method used to quantify the severity of the spinal curvature [2, 10]. In general, individuals with a Cobb angle less than 25° are observed, those between 25° to 45° are braced, and for those with curves greater than 45°, a spinal surgery is recommended [2, 11, 12]. The effectiveness of standard-of-care treatments is determined by limiting curve progression to 5° or less [3, 13]. However, aesthetic appearance is crucial for patients and parents [14–16]. The International Society on Scoliosis Orthopaedic and Rehabilitation Treatment (SOSORT) suggests aesthetics as among the priorities of objective AIS treatment [17].

Exercise can improve aesthetic outcomes [17–19]. The Schroth method is aimed at correcting posture through recalibration of a normal postural alignment and corrective breathing techniques [20, 21]. An important component of the Schroth method is auto-correction, which is the application of active postural realignment of the spine in 3D to reduce postural asymmetry [21]. Schroth SSE can reduce curve progression, curve severity and improve muscle endurance [22–25]. More evidence is needed on the efficacy of the Schroth program on cosmetic outcomes [26].

The Cobb angle obtained from radiograph assessments has several limitations. The outcome measured from a 2D posterior-anterior view does not fully capture the 3D nature of the spinal curvature of AIS [10, 27]. Research indicates that radiological parameters correlate poorly with patients' subjective perception of body image [28–30]. Additionally, frequent radiographs are required to monitor curve progression, which increase the risk of developing certain types of cancer [31, 32].

Thorough research on cosmetic outcomes is needed. Less than 3.5% of the literature on AIS addresses this topic [19]. This gap is partly attributed to the limited methodologies for assessing cosmetic and posture outcomes [17, 19]. Self-reported perception of the back condition during treatment has gained increased attention, leading to the development of questionnaires designed to evaluate subjective perception of appearance in individuals with scoliosis [33], as well as objective measurement tools, including back photography, trunk asymmetry scales or surface topography (ST) systems [11, 34–36].

A markerless ST has been developed to characterize the trunk asymmetry of patients with AIS without ionizing radiation [11, 37–39]. Used in conjunction with radiographs, ST can enhance the management of scoliosis and reduce the risk associated with radiation exposure by limiting the frequency of x-ray scans [39]. The ST markerless technique takes into account the entire 3D torso, quantifies the trunk asymmetry affected by AIS and presents a visual representation using a deviation colormap map (DCM) [37, 40]. Areas of asymmetries are identified from the DCM, and extracted parameters from these areas are used to predict severity and progression [37, 39]. Parameters include the maximum deviation (MaxDev) within an asymmetry patch at the level of each curve and the root mean square (RMS) of the deviations measured in that patch [11, 37–39, 41].

It is unclear how much change in ST measures is needed for patients to perceive an improvement in their back condition. During the treatment, patients may experience changes in their surface asymmetries, which can vary in magnitude. However, not all changes are recognized or deemed important by patients. The minimal change in a measurement that patients consider significant is the Minimal Clinically Important Change (MCIC) [42, 43]. Clinicians rely on MCIC to assess the effectiveness of an intervention and guide their decision-making [43]. There is a lack of information concerning the MCIC of ST parameters, limiting its use as a tool to evaluate cosmetic appearance.

This study aimed to determine the association between perceived improvement in back status and changes in ST asymmetry in patients with AIS undergoing a Schroth intervention, as well as the ability of ST asymmetry measures to detect improvements perceived as important by patients in response to the treatment.

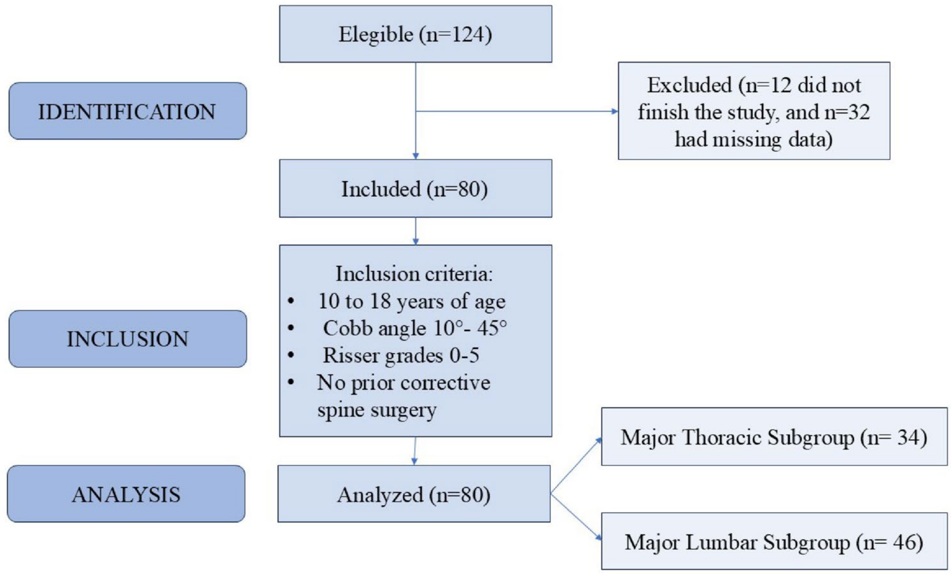
Methods

Data acquisition

This is a secondary analysis from a randomized controlled trial (RCT). The RCT was conducted to evaluate the effect of a six month Schroth intervention added to the standard of care on curve severity, quality of life, and torso asymmetry of patients with AIS [24, 25, 30, 44]. One hundred twenty-four participants were recruited from a Scoliosis Clinic and randomized into two groups: the standard of care group (n = 60) and the Schroth group (n = 64).

The Schroth group received six months supervised Schroth SSE intervention, which included individual weekly sessions overseen by a trained Schroth therapist and daily 30- to 45-minute home exercises. The Schroth intervention was prescribed in addition to the standard of care (observation or bracing). A detailed description of the Schroth intervention was previously published [45, 46]. The

Fig. 1 STROBE flow chart



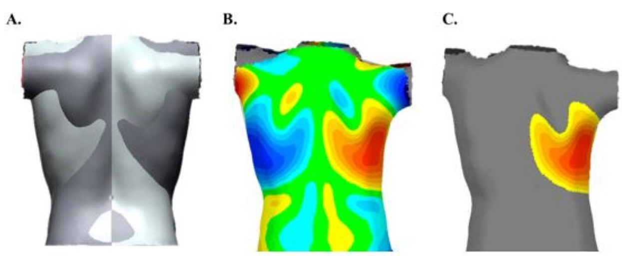


Fig. 2 ST analysis depicting **A**) best fit alignment of original (silver) and reflected torso (grey), **B**) deviation color map and **C**) isolated patch for obtaining RMS and MaxDev parameters

control group only received standard of care in the first six months but was offered six months of Schroth intervention in the latter half of a one-year follow-up.

The criteria for including potential participants were as follows: 10 to 18 years of age at baseline, Cobb angle between 10° and 45°, Risser grade between 0 and 5, and no prior corrective spine surgery. A STROBE flow chart can be found in Fig. 1. The study was approved by the University of Alberta Health Research Board (pilot study approval Pro00011552, extended study approval Pro00043397), Trial Registration NCT01610908.

Measurements

Global rate of change

The Global Rate of Change (GRC) is a measure of change in patients' perceived health condition over time indicating whether their condition worsened, remained unchanged, or improved [47]. The GRC has good test-retest reliability and validity [47]. This study used the 15-point GRC scale to ascertain the participants' impression of their back condition. The GRC scaled from − 7 (a great deal worse) to + 7 (a great deal better). Intermediate values of -1 represented "a tiny bit worse," 0 was "about the same," and + 1 was "a tiny bit better." After six months, participants were asked using the GRC scale: "Please rate the overall condition of your back from the time you began the treatment until now." The radiograph findings were not disclosed to the participants, and the GRC at 6-month follow-up. Based on the GRC ratings, two groups were defined: improved (+ 2 little bit to + 7 very great deal better) and not improved, which represents no change or a deteriorated back condition (+ 1 tiny bit better to -7 great deal worse) [30].

Asymmetry parameters

Surface torso scans were obtained at baseline and six months using four stationary VIVID 910 3D laser Minolta scanners, capturing the torso's front, back, and side views. The patients' arms were maintained at 90 degrees of shoulder elevation as they stood in a frame. The four views were merged to obtain a 3D model. The region below the posterior superior iliac spine, the head, neck, and shoulders from the scapula were cropped out, followed by noise filtering and smoothing of the torso [11, 38]. The ST technique involved mirroring the 3D cloud points of the torso model over the sagittal plane. This reflected model was then aligned with the original model. Using the iterative least-squares method, the reflected torso coordinates are transformed to minimize the distance between the reflected and original torsos (Fig. 2a) [11, 38–40].

The asymmetries were represented using a deviation colour map (DCM) obtained from the distance between the original and reflected torsos. A deviation of ± 3 mm was deemed typical (green in Fig. 2b) and applied in the DCM to reveal patch areas of asymmetries caused by the spinal curvature (shades of yellow/red and blue in Fig. 2b and c) [11]. In addition, a threshold of 9.33 mm was used in certain circumstances (i.e. when the maximum deviation in a patch was > 9.33) to improve the separation of asymmetry patches [41]. ST parameter measurements were obtained using the patch corresponding to the location of largest curve. Root mean square (RMS) and Maximum deviation (MaxDev) were determined from the isolated patch. ST measurements were computed from the same patch at baseline and six months scans. Finally, the change in ST parameters between scans was recorded.

Curve classification

Participants' curve patterns were classified using the Schroth classification algorithm [46, 48]. A major thoracic curve and a balanced pelvis characterize a TS or TLS classification and may include a minor lumbar curve. A THS classification features a single thoracic curve with an imbalanced pelvis. A major lumbar curve with a balanced pelvis defines the LTS curve. An LHTS classification characterizes a major thoracolumbar or lumbar curve with an imbalanced pelvis and may include a minor thoracic curve. Participants with major thoracic curves without (TS and TLS types) and with pelvic imbalance (THS types), respectively, were combined into one subgroup. Participants with major lumbar curves without (LTS) and with pelvic imbalance (LHTS), were combined into another subgroup. The topographical classification of the Schroth subgroups is an approximation and not a one-to-one match, as the Schroth classification reflects a three-dimensional functional pattern of the torso, whereas the standard classification is based on anatomical apex location of the curve.

Statistical analysis

Pearson correlation analysis was used to quantify the correlation between the change in ST parameters and the GRC scores. The changes in ST parameters with a significant correlation to the GRC were further analyzed to determine their MCICs. The anchor-based method to estimate MCIC is a well-established approach linking an outcome measure to an external criterion (anchor) that distinguishes participants with important improvement or deterioration from participants with no important change [49]. In this study, the GRC was used as the anchor to determine the minimum change in ST parameters that corresponds to patient's perceived improvement of overall back condition. A receiver-operating characteristic (ROC) curve was used to compare the change in ST parameters and the GRC grouped (as improved and not improved) by plotting the sensitivity and false positive rate at various decision thresholds. The ROC curve was used to determine the MCIC threshold for each parameter with the best balance of sensitivity and false positive rate. The ST parameter threshold change represents the cutoff value that best distinguishes between improved and not improved (no change or deteriorated). The threshold value is determined by selecting the point nearest to the top left corner of the curve on the plot of sensitivity over the false positive rate. The ST thresholds' diagnostic accuracy with the ground truth of perceived improvement based on GRC was also examined. Curve type-based subgroup analyses were also carried using the Schroth curve type classification algorithm [48]. ROC analysis of the lumbar and thoracic curves was performed to ascertain the MCICs for each kind of curve.

Results

Eighty participants made up the sample size from the recruited 124 participants in the study, after excluding 12 who did not finish the study and 32 who had missing data. Intention-to-treat analysis was not conducted since it was important to determine the MCICs of the ST parameters of participants who followed the protocol as intended. Participants had a mean age of 13.3 ± 1.7 years at baseline and ST parameters RMS and MaxDev of 10.6 ± 4.8 mm and 15.8 ± 8.2 mm, respectively (Table 1). Treatment distribution in the sample was as follows: 13 (16% of the sample) participants were under observation, 26 (33%) participants were wearing a brace, 16 (20%) participants underwent Schroth therapy, and 25 (31%) participants were wearing a brace and had Schroth intervention. In addition, 8 (10%) participants were classified as TS or TLS (major thoracic with balanced pelvis), 26 (33%) as THS (major thoracic with imbalanced pelvis), 10 (13%) as LTS (major lumbar with balanced pelvis), and 36 (45%) participants as LHTS (major lumbar with imbalanced pelvis) curve types (Table 1). Table 2 reports additional description of curves based on the apex location in the major thoracic and lumbar curves subgroups.

The average change in RMS and MaxDev was −0.43 ± 3.2 mm and −1.13 ± 6.4 mm, respectively. The mean GRC was 2.11 ± 3.1. The Pearson correlation between GRC and ΔRMS was significant (r=-0.510, p < 0.001, Table 3; Fig. 3). Likewise, the correlation between the GRC and ΔMaxDev was significant (r=-0.409, p < 0.001, Table 3; Fig. 3). Based on the GRC scores, 42 participants reported improved overall back condition, and 38 participants reported deterioration or no change over the six-month intervention. RMS and MaxDev for participants who reported improved posture decreased by 1.76 ± 2.9 mm

Table 1 Baseline characteristics for the whole sample and split by curve type

Characteristic	Total Sample		Major Thoracic Subgroup (TS, TLS, THS)		Major Lumbar Subgroup (LTS, LHTS)	
Sample Size	80		TS and TLS (8;10%)	THS (26;33%)	LTS (10;13%)	LHTS (36;45%)
Age (years)	13.3 ±1.7		13.4 ±1.7		13.2 ±1.7	
Height (m)	156.8 ± 9.5		158.1 ± 7.3		155.7 ± 10.8	
Weight (kg)	45.2 ± 9.1		46.4 ± 8.0		44.3 ± 9.9	
Cobb angle (°)	27.9 ± 8.9		28.8 ± 8.7		27.3 ± 9.1	
RMS (mm)	10.6 ± 4.8		11.9 ± 5.0		9.7 ± 4.6	
MaxDev (mm)	15.8 ± 8.2		17.3 ± 7.8		14.7 ± 8.3	
Prescribed Treatment	Observation (13;16%)	Exercise alone (16;20%)	Observation (6;18%)	Exercise alone (7;21%)	Observation (7;15%)	Exercise alone (9;20%)
	Braced alone (26;33%)	Braced + Exercise (25;31%)	Braced alone (11;32%)	Braced + Exercise (10;29%)	Braced alone (15;33%)	Braced + Exercise (15,33%)

Table 2 Topographic curve classification characteristics within the Schroth major thoracic and major lumbar subgroup

Schroth Subgroup		Total number of curves	Thoracic	Thoracolumbar	Lumbar
Major thoracic	**TS and TLS**	15	11	0	4
	THS	37	23	3	11
Major lumbar	**LTS**	16	7	6	3
	LHTS	49	19	20	10

and 3.29 ± 6.5 mm, respectively. Alternatively, RMS and MaxDev for those who reported deteriorated or no change in posture increased by 1.03 ± 3.0 mm and 1.26 ± 5.6 mm, respectively.

The ROC curve, displaying sensitivity and specificity to detect GRC reports of improvements for various changes in RMS and MaxDev are shown in Fig. 4. The area under the curve (AUC) was 0.746 (95%CI 0.638;0.853) for ΔRMS and 0.717 (95% CI 0.605;0.829) for ΔMaxDev (Table 4).

The estimated RMS MCIC from the ROC curve had a sensitivity of 67% and a specificity of 74%. This corresponds to a change of RMS with the best ability to detect participants perceiving improvement of -0.27 mm. The estimated MaxDev MCIC had a sensitivity of 64% and a specificity of 68%, corresponding to a decrease in MaxDev by 0.49 mm to detect perceived improvement. The accuracy to detect perceived improvement on the GRC of meeting both the RMS (decrease ≥ 0.27 mm) and MaxDev MCIC (decrease ≥ 0.49 mm) was 68% with a sensitivity of 62% and a specificity of 74%. (Table 5).

Analysis by curve types

Participants with major thoracic curves without (TS and TLS types) and with pelvic imbalance (THS types), respectively, were combined into one subgroup. Participants

Table 3 Correlation coefficients for the association between the change in ST parameters (ΔRMS, ΔMaxDev) and the patient reported GRC scores

	Complete Sample **(n=80)**		Major Thoracic Subgroup **(TS, TLS, THS, n=34)**		Major Lumbar Subgroup **(LTS, LHTS, n=46)**	
ST Parameter	Pearson Correlation	*P*-value	Pearson Correlation	*P*-value	Pearson Correlation	*P*-value
ΔRMS	-0.510	**<0.001**	-0.390	**0.023**	-0.495	**0.010**
ΔMaxDev	-0.409	**<0.001**	-0.453	**0.007**	-0.562	**0.003**

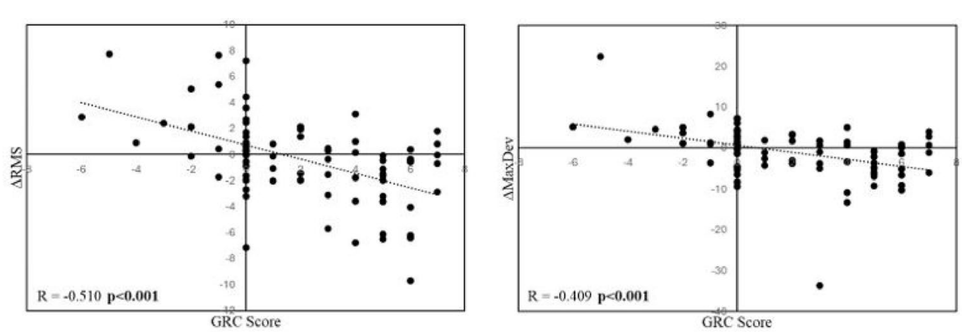


Fig. 3 GRC scores and the corresponding change in RMS and MaxDev with the correlation r value reported

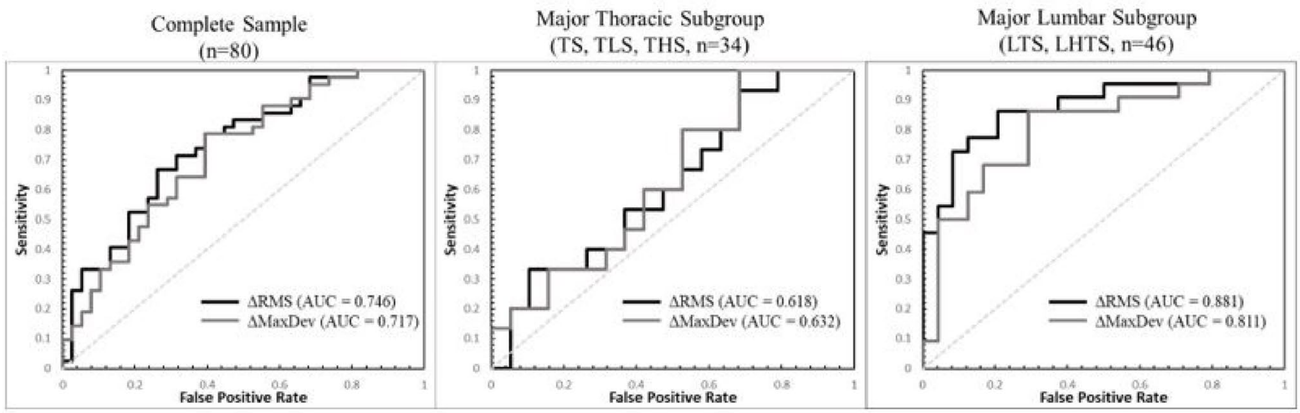


Fig. 4 Receiver operating characteristics (ROC) curves of patient perceived improvement (GRC≥2) at various cutoff points of change in RMS and MaxDev

Table 4 Responsiveness results and minimally important changes (MCIC) of ST parameters from receiver operating characteristic (ROC) analysis from the complete group and curve type analyses

	Complete Sample (*n*=80)	Major Thoracic Subgroup (TS, TLS, THS, *n*=34)	Major Lumbar 4c/4cp Subgroup (LTS, LHTS, *n*=46)
Mean GRC (-7 to 7)	2.11 ± 3.1	1.88 ± 2.7	2.28 ± 3.3
RMS parameter			
ΔRMS (mm) if Perceived Improvement (GRC ≥2)	-1.76 ± 2.9	-1.74 ± 2.4	-1.77 ± 3.1
ΔRMS (mm) if Perceived No change/ Deteriorated (GRC<2)	1.03 ± 3.0	-0.36 ± 3.0	2.42 ± 2.4
AUC	0.746 (0.638;0.853)	0.618 (0.427;0.808)	0.881 (0.777;0.973)
MCIC (mm)	-0.27	-0.58	-0.26
MaxDev parameter			
ΔMaxDev (mm) if Perceived Improvement (GRC ≥2)	-3.29 ± 6.5	-3.18 ± 4.5	-3.35 ± 7.4
ΔMaxDev (mm) if Perceived No change/ Deteriorated (GRC<2)	1.26 ± 5.6	0.17 ± 6.8	2.34 ± 3.9
AUC	0.717 (0.605;0.829)	0.632 (0.444;0.820)	0.811 (0.667;0.931)
MCIC (mm)	-0.49	-1.32	-0.61

Table 5 Accuracy results of classifying perceived improvement and no change/deteriorated (GRC < 2) using RMS and MaxDev MCICs for the entire sample, thoracic major curves subgroup, and lumbar major curves subgroup

Complete Sample (*n*=80)			
	ΔRMS ≤ -0.27 mm	ΔMaxDev ≤ -0.49 mm	ΔRMS≤ -0.27 mm and ΔMaxDev≤ -0.49 mm
Accuracy	0.70	0.66	0.68
Sensitivity	0.67	0.64	0.62
Specificity	0.74	0.68	0.74
Major Thoracic Subgroup (TS, TLS, THS, *n*=34)			
	ΔRMS ≤ -0.58 mm	ΔMaxDev ≤ -1.32 mm	ΔRMS≤ -0.58 mm and ΔMaxDev≤ -1.32 mm
Accuracy	0.56	0.56	0.59
Sensitivity	0.60	0.60	0.58
Specificity	0.53	0.53	0.59
Major Lumbar Subgroup (LTS, LHTS, *n*=46)			
	ΔRMS ≤ -0.26 mm	ΔMaxDev ≤ -0.61 mm	ΔRMS≤ -0.26 mm and ΔMaxDev≤ -0.61 mm
Accuracy	0.83	0.76	0.80
Sensitivity	0.73	0.68	0.68
Specificity	0.92	0.83	0.92

with major lumbar curves without (LTS) and with pelvic imbalance (LHTS), were combined into another subgroup. For participants with major thoracic curves, the correlation between GRC and ΔRMS was significant (*r*=-0.390, $p = 0.023$). Likewise, the correlation between the GRC and ΔMaxDev was significant (*r*=-0.453, $p = 0.007$) (Table 3). RMS and MaxDev for participants who reported improved posture decreased by 1.74 ± 2.4 mm and 3.18 ± 4.5 mm, respectively. Alternatively, the change in RMS and MaxDev for those who reported deteriorated or no change in posture was −0.36 ± 3.0 mm and 0.17 ± 6.8 mm, respectively. The AUC was 0.618 (95% CI 0.427;0.808) for ΔRMS and 0.632 (95% CI 0.444;0.820) for ΔMaxDev (Table 4). From the ROC analysis, a minimal decrease of 0.58 mm for RMS was selected as MCIC in this subgroup, yielding a sensitivity of 60% and a specificity of 53%. In addition, a minimal decrease of 1.32 mm for MaxDev was selected, yielding a sensitivity of 60% and a specificity of 53%. Sensitivity and specificity of 58% and 59% are obtained when the thoracic patches decrease in both RMS and MaxDev below the MCIC thresholds (Table 5).

For participants with major lumbar curves, the correlation between GRC and ΔRMS was significant (r=-0.495, p = 0.010). Likewise, the correlation between the GRC and ΔMaxDev was significant (r=-0.562, p = 0.003) (Table 3). RMS and MaxDev for participants who reported improved posture decreased by 1.77 ± 3.1 mm and 3.35 ± 7.4 mm, respectively. Alternatively, the worsening changes in RMS and MaxDev for those who reported deteriorated or no change in posture were 2.42 ± 2.4 mm and 2.34 ± 3.9 mm, respectively. The AUC was 0.881 (95% CI 0.777;0.973) for ΔRMS and 0.811 (95% CI 0.667;0.931) for ΔMaxDev (Table 4). The ROC analysis selected as MCIC a minimal decrease of 0.26 mm for RMS, yielding a sensitivity of 73% and a specificity of 92%. In addition, a MCIC corresponding to a minimal decrease of 0.61 for MaxDev was selected, yielding a sensitivity of 68% and a specificity of 83%. Sensitivity and specificity of 68% and 92% are obtained when the thoracic patches decrease in both RMS and MaxDev below the thresholds (Table 5).

Discussion

The significant correlation observed suggests that patients' perceptions of their backs as reported by the GRC score, are accurately reflected in the changes in ST parameters RMS and MaxDev. It was expected that there would be a negative correlation since a positive GRC score (perceived improvement) is shown by negative ΔRMS and ΔMaxDev values (improved symmetry). In addition, the outcome (ST measures) and the target (GRC) correlated well ($r > 0.30$), which is the recommended minimal correlation value to allow for reliable MCIC estimates [43]. Few studies have examined the relationships between surface topographic measures and patient-reported back perception. To our knowledge, no studies have assessed the correlation between ST parameters from the markerless techniques and the patients' perception of their back status during intervention.

The MCICs with the highest association to participants perceiving improvement yielded moderate sensitivity and specificity values. The low MCIC values of RMS and MaxDev indicate that even participants with little to no change in their ST parameters still perceived improvement in their back condition. Those who experienced a decrease in ST parameters beyond the MCICs threshold also reported improvement. Conversely, if ST parameters worsened and increased over time, participants perceived a deterioration in their back condition.

The accuracy of associations between patients' perception and the RMS and MaxDev thresholds were compared. The sensitivity was higher using the RMS threshold compared to the MaxDev threshold. This suggests that, compared to MaxDev, RMS showed higher correlation with positive changes in back condition according to the GRC. Likewise, the specificity was greater using the RMS MCIC, indicating a notable association with patients′ perceived lack of improvement (no change or deterioration). In general, when the criteria of both RMS and MaxDev MCICs show association with the perceived back condition, sensitivity decreases, while specificity increases but is equal to the specificity when only the RMS threshold is used.

Participants with major lumbar curves (LTS and LHTS) exhibited a stronger association between surface topography and perceived improvement, as evidenced by the higher AUC. Participants with major thoracic curves (TS, TLS, and THS) show a less clear relationship, with the surface topography parameters having a more moderate correlation with perceived improvement. In contrast to the changes in ST parameters in major thoracic curve types, larger changes in exterior surface asymmetries were found in the major lumbar curve types after 6 months of intervention. An AUC of at least 0.70 is recommended for an appropriate responsiveness study [49]. The AUCs of the complete sample and lumbar subgroups ROC curves were greater than 0.7. The AUC of the thoracic subgroup was less than the recommended value (ΔRMS AUC 0.618, ΔMaxDev AUC 0.632). The observed difference between the major thoracic and major lumbar curve subgroups could be attributed patients' perceptions of what constitutes a meaningful change in their backs. It is possible that participants can notice changes for curves in the lumbar regions more easily than curves in the thoracic region. Another explanation is that the treatment has achieved more changes in the lumbar region than in the thoracic region, where the latter is more rigid and more structural than postural. Mean changes in ST parameters measured over the 6 months intervention between participants classified as improved and not improved based on their GRC score revealed clear differences in all analyses (complete sample, thoracic subgroup, and lumbar subgroup). Despite the decreased responsiveness of the major thoracic subgroup, participants with perceived improvement had a decreased RMS and MaxDev by 1.74 mm and 3.18 mm, respectively, while the not improved group had a slight decreased RMS by 0.36 mm and an increase in MaxDev by 0.17 mm. However, sensitivity and specificity were overall lower in the major thoracic subgroup consistent with the poorer AUC. Clinicians working with patients with major thoracic curves may interpret smaller changes as clinically important to their patients compared to those with major lumbar curves where more changes are needed to reach a perceived improvement (but the latter has better sensitivity and specificity for perceived improvement).

The MCICs in this study were estimated using the GRC as the anchor, a subjective measure reflecting the patient's point of view. The GRC score is not a continuous measurement and is recorded at follow-ups. Participants make their impressions of their overall back condition over time and, therefore, might not accurately recall the state of their back condition at the beginning of the trial compared to the present time [47]. Participants may have overestimated or underestimated their GRC, which might be the reason for the less than perfect correlation between the GRC scores and the ST parameters' asymmetry.

Some limitations were identified in this study. First, the relatively small sample size restricted the ability to conduct more subgroup analyses, particularly the differentiation between participants with and without pelvic imbalance within the lumbar and thoracic subgroups. The sample size analyzed was insufficient to examine MCIC for different curve types and prescribed treatment due to the high variability of curve magnitude treatment type. However, this heterogeneity reflects the spectrum of conservative care typically offered to adolescents with idiopathic scoliosis. While a larger sample would have allowed subgroup analyses by treatment type or curve severity, the current study aimed to establish MCIC estimates applicable across the continuum of conservative care used in clinical practice. In addition, blocked randomization during participant recruitment ensured a balanced representation of patients with major thoracic and major lumbar curves, which allowed us to examine subgroup responsiveness by curve type despite overall sample size limitations.

Treatment type and curve magnitude could potentially influence both ST parameters and patients' perception of change measured by the GRC. MCIC analyses could be conducted within each treatment subgroup to examine whether thresholds differ according to treatment exposure. However, the sample size within each treatment category was relatively small, particularly when further divided by the anchor categories (improved, stable, deteriorated). Anchor-based MCIC estimation requires a sufficient number of participants in each anchor group to produce stable ROC estimates, and in this study, combining stable and worsening cases is a sample size limitation that must be recognized. Participants prescribed with Schroth SSE without a brace showed changes in RMS by -0.57 ± 3.0 mm and MaxDev by -2.80 ± 9.1 mm, compared to -1.72 ± 3.5 mm and −2.22 ± 6.5 mm, respectively, in those prescribed with Schroth SSE while wearing a brace. Participants in the Schroth SSE subgroup who reported improvement showed a reduction in RMS (-1.41 ± 2.6 mm) and MaxDev (-4.11 ± 9.9 mm), while those reporting no change or deterioration showed increased RMS (1.97 ± 3.1 mm) and MaxDev (1.15 ± 4.8 mm). Similarly, among braced participants with Schroth SSE, those reporting improving showed decreased RMS (-2.32 ± 3.3 mm) and MaxDev (-3.29 ± 4.5 mm), while those reporting no change or deterioration showed increased RMS (0.18 ± 3.9 mm) and MaxDev (1.17 ± 10.8 mm) parameters. Future studies may determine MCIC within different treatment groups and curve magnitude. In addition, the use of the Schroth classification, although relevant because patients underwent Schroth therapy, may limit the generalizability of these findings and may not be applicable to different scoliosis phenotyping classifications.

Another limitation is the need for more consensus regarding the methodology for estimating the MCIC. Our study aimed to determine the MCICs using ROC analyses, which revealed optimal thresholds for surface topography parameters associated with perceived improvement. Several methods are available for estimating the MCIC; the anchor-based and distribution-based methods are the most common, though there has yet to be a consensus on the best method to determine the MCIC [49]. The anchor-based method relies on external criteria, such as patient-reported outcomes, as a reference point for defining a meaningful change. The open nature of the question, when participants are answering the GRC, may be another limitation. Participants may be evaluating shoulder asymmetries and waistline imbalance as factors affecting overall back condition. The ST parameters extracted from the thoracic or lumbar patches do not reflect the changes in the shoulders and waist asymmetries. The surface scans were cropped during preprocessing, and the ST patches on the shoulders and pelvis were excluded from the analysis. Finally, a validation study should be conducted to confirm the overall accuracy of the MCIC estimates.

Despite these limitations, our study contributes valuable information regarding the relationship between ST parameters and perceived improvement in back condition, particularly in AIS treatment. The strong correlation between changes in root mean square (RMS) and maximum deviation (MaxDev) and patients' self-reported outcomes underscores the potential clinical relevance of surface topography measurements in assessing treatment efficacy. This study determined meaningful changes in ST parameters after six months of Schroth scoliosis specific exercises. Rather than assessing long term treatment outcomes or disease progression, identifying clinically meaningful changes over a six-month period is highly relevant for clinicians who monitor patients regularly and adjust treatment strategies over shorter intervals. Detecting meaningful improvement within this timeframe can help guide clinical decision-making, motivate patients, and inform treatment adjustments. In addition, scoliosis curves can progress by up to 9° within six months during peak growth, making this period clinically meaningful for detecting both progression and treatment response.

Conclusion

The markerless surface topography (ST) technique has been proposed as a tool for assessing torso asymmetries providing objective measures of posture. In this study, ST-derived parameters demonstrated a relation with self-reported GRC scores in evaluating back condition. Our fundings demonstrated the potential of surface topography parameters, particularly RMS and MaxDev, as objective measures for capturing patient-perceived changes in back conditions.

Author contributions N.M., J.M.G-R., S.S, E.P, Q.M & L.W. made substantial contributions to the conception or design of the work; or the acquisition, analysis, or interpretation of data; or the creation of new software used in the work.N.M., J.M.G-R., S.S, E.P, Q.M & L.W. drafted the work or revised it critically for important intellectual content.N.M., J.M.G-R., S.S, E.P, Q.M & L.W. approved the version to be published.N.M., J.M.G-R., S.S, E.P, Q.M & L.W. agree to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

Data availability No datasets were generated or analysed during the current study.

Declarations

Competing interests The authors declare no competing interests.

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Authors and Affiliations

Nada Mohamed[1] · José María González Ruiz[1,2] · Sanja Schreiber[3] · Eric Parent[3] · Qipei Mei[4] · Lindsey Westover[1]

✉ José María González Ruiz
josemar1@ualberta.ca

Nada Mohamed
nada1@ualberta.ca

Sanja Schreiber
sbosnjak@ualberta.ca

Eric Parent
eparent@ualberta.ca

Qipei Mei
qipei.mei@ualberta.ca

Lindsey Westover
lwestove@ualberta.ca

1 Department of Mechanical Engineering, University of Alberta, Edmonton, Canada

2 3D-Data Department, Society for the Advancement of Applied Computer Science, Berlin, Germany

3 Department of Physical Therapy, Faculty of Rehabilitation Medicine, University of Alberta, Edmonton, Canada

4 Department of Civil and Environmental Engineering, University of Alberta, Edmonton, Canada