Spine

SPINE Volume 37, Number 11, pp 957–965

Accuracy, Reliability, and Validity of a 3-Dimensional Scanner for Assessing Torso Shape in Idiopathic Scoliosis

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Study Design. Prospective cohort with concurrent controls.

Objective. To establish accuracy, reliability, and validity of the Vitronic 3D Body Scanner for the evaluation of torso asymmetry in patients with idiopathic scoliosis.

Summary of Background Data. Improved appearance is an important expectation of treatment for patients with scoliosis and their parents. Despite being the "gold standard" for quantifying outcomes, Cobb angles do not explain perception of appearance or quality of life. Surface topography is an attractive noninvasive alternative to radiography but has not been studied in the context of patient-centered outcomes.

Methods. Thirty-six adolescents with idiopathic scoliosis undergoing surgical correction had pre- and postoperative radiographs and evaluation of standing posture, torso surface shape, and responses to the Scoliosis Research Society-22 and Spinal Appearance Questionnaire. Twenty-one adolescents without scoliosis were evaluated for comparison. Scanner accuracy was assessed by scanning an object of known dimensions. Within-session reliability of body shape measures constructed from scan data was assessed. Discriminant validity was assessed by examining pre- to postoperative differences. Concurrent validity was examined through correlations of scan measures with radiographs, optoelectronic measures of posture, and self-report responses to the Scoliosis Research Society-22 and Spinal Appearance Questionnaire.

Results. Scan system measurement error was 1.74 ± 1.56 mm. Within-session reliability was excellent for the control (intraclass correlation coefficient = 0.83) and scoliosis (intraclass correlation coefficient = 0.94) groups. Medial/lateral torso shift, rotation, and right/left asymmetry differed significantly among the preoperative, postoperative, and control groups (analysis of variance, $P < 0.05$). Torso asymmetry measures correlated with radiographical measures ($r = 0.43$–0.51), optoelectronical measures of posture and symmetry ($r = 0.33$–0.75), and appearance and quality-of-life domains of the Scoliosis Research Society-22 ($r = 0.35$–0.64) and the Spinal Appearance Questionnaire ($r = 0.48$–0.67).

Conclusion. The Vitronic 3D Body Scanner has sufficient accuracy, reliability, and validity to monitor torso asymmetry due to scoliosis. Scan-based measures differentiate between normal and pathological and between preoperative and postoperative body shape and show good correlation with measures of appearance and quality of life.

Key words: scoliosis, surface imaging, trunk shape, accuracy, reliability, validity. **Spine 2012;37:957–965**

Idiopathic scoliosis (IS) is a complex 3-dimensional deformity of the spine. Goals of surgical management include stabilizing curve progression, achieving permanent correction, improving appearance and perceived functional outcomes related to physical and psychosocial health, and reducing the potential for development of future pain and disability.[1] Torso deformities of IS include rib and scapular prominences, asymmetrical shoulder height and angle, chest wall deformity, and anterior/posterior and lateral shifts of the trunk relative to the pelvis.[2] In a study of preferences and concerns regarding IS, "looking better" was second only to "being free from pain or disability as an adult" as the most important expectation of treatment for patients and their parents.[3]

Measuring the outcomes of surgically corrected scoliosis is complex and may best be accomplished by incorporating both physician- and patient-related objectives. The surgeon aims to stabilize the deformity, minimizing long-term consequences of progression. The patient hopes for restoration of normal appearance and for maximizing function, while minimizing pain. The parent expects improved function and long-term stabilization that may decrease caregiver burden. Each perspective is different, yet a valid interpretation of desired outcome.

The "gold standard" for quantifying magnitude of deformity and change over time remains determination of Cobb angles. However, such radiographical indices reflect

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Acknowledgment date: April 5, 2011. First revision date: August 2, 2011. Acceptance date: September 19, 2011.

The manuscript submitted does not contain information about medical device(s)/drug(s).

Stryker Spine funds were received to support this work.

No benefits in any form have been or will be received from a commercial party related directly or indirectly to the subject of this manuscript.

Human subject protection for this project was approved by the Baystate Medical Center IRB.

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DOI: 10.1097/BRS.0b013e31823a012e

2-dimensional projections of 3-dimensional deformity and underestimate other aspects such as rib hump.[4] Furthermore, little correlation exists between radiographic assessment and clinical outcome.[5] Mechanical,[4] photographic,[6] computed tomographic,[7] and light-based imaging techniques[8–10] have been developed over the years to minimize radiation exposure and offer insight to the 3-dimensional aspects of the deformity. These studies have demonstrated that normal appearance is not fully restored by instrumentation and fusion, Cobb angles do not explain patient or parent perception of 3-dimensional deformity, and patient well-being is not accurately reflected by Cobb angles.[11]

The 3-dimensional characteristics of IS make it paramount to establish tools for assessing outcomes that effectively bridge the gap between what the physician sees on the interior and what the patient sees on the exterior. Surface topography and optoelectronic measurements are attractive noninvasive alternatives to radiography but have not been studied in the context of patient-centered outcomes. The purpose of this investigation was 2-fold: first, to establish the accuracy, reliability, and validity of the Vitronic 3D Body Scanner for the evaluation of axial skeletal deformity in patients with IS and second, to examine relationships among objective measures of surface topography with subjective measures of appearance and quality of life.

MATERIALS AND METHODS

Thirty-six adolescents (26 females and 10 males) with juvenile (n = 9) or adolescent (n = 27) onset of IS who received posterior instrumentation and fusion between April 2006 and December 2008 were prospectively followed for 18.7 months (SD, 7.7; range, 6–32) after surgery. At surgery, patients had a mean age of 14.7 years (SD, 1.8; range, 10.8–17.7). Preoperative primary Cobb angles averaged 59.2° (SD, 13.8; range, 49–108); 31 (86%) were right primary curves. A control group of 21 adolescents (14 females and 7 males) without scoliosis was recruited, with a mean age of 13.9 years (SD, 3.1; range, 8.3–19.4). Participant characteristics are shown in Table 1. This project received approval from the local institutional review board. Participants signed consent and Health Insurance Portability and Accountability Act Privacy Rule documents as appropriate.

TABLE 1. Participant Characteristics

Characteristic	Scoliosis	Normal
Sex, n (%)		
Male	10 (27.8)	7 (33.3)
Female	26 (72.2)	14 (66.7)
Age (yr), mean (SD)	14.7 (1.8)	13.8 (3.1)
Follow-up time in months, mean (SD)	18.4 (7.7)	
Onset, n (%)		
Juvenile	9 (25.0)	
Adolescent	27 (75.0)	
Lenke classification, n (%)		
Curve type		
1	12 (33.3)	
2	12 (33.3)	
3	5 (13.9)	
4	2 (5.6)	
5	2 (5.6)	
6	3 (8.3)	
Coronal modifier		
A	17 (47.2)	
B	9 (25.0)	
C	10 (27.8)	
Sagittal modifier		
–	8 (22.2)	
N	21 (58.3)	
+	7 (19.4)	

Pre- and postoperative evaluation of radiographic spinal deformity, standing posture, circumferential surface torso shape, and responses to the Scoliosis Research Society (SRS-22) and Spinal Appearance Questionnaire (SAQ) were completed for all participants with scoliosis. The control group completed all evaluations except radiographs and the SAQ. On the basis of examination of preoperative posteroanterior and bending radiographs, curve type was determined according to Lenke classification system. The largest Cobb angle was recorded as the primary curve magnitude to characterize curve severity.

Standing posture was evaluated using an optoelectronic motion capture system according to a protocol previously described.[12] In brief, positions of reflective targets attached to the body at specific anatomic landmarks were used to determine standing symmetry relative to a central weight-bearing line, as well as tilt, obliquity, and rotation of the upper torso and shoulders relative to the pelvis.

Circumferential surface torso shape was recorded using a Vitus Smart 3D Body Scanner (Vitronic, Wiesbaden, Germany). Participants stood on a platform within a 1.6 ×1.8-m measurement volume, with hands at the side and arms slightly abducted. Three trials were captured during each test session. Data were analyzed using custom software to sequentially view individual horizontal scan "slices," each composed of several hundred data points (a "point cloud"), separated by 3.6 mm between successive slices.

To analyze a scan (Figure 1), first an ellipse was fit to the point cloud for a reference slice defined at the level of the posterior superior iliac spines. The center of this ellipse and orientation of its principal axis served as reference for all measurements. The upper extent of useful data was identified on the basis of a clear definition between the torso and arms in the upper thoracic region. The software then fit an ellipse

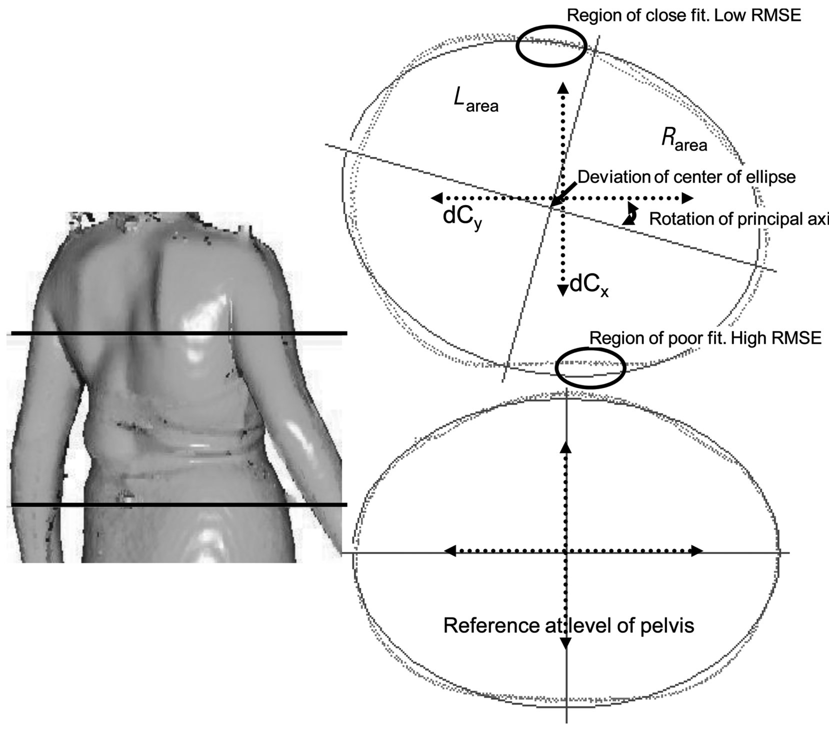

Figure 1. An ellipse (shown as a solid line in each figure above right) is fit to each scan "slice" composed of several hundred points (a point cloud) that measure the shape of the torso. A slice at the level of the pelvis (lower right figure) is used as a reference defined by the origin of the center of the ellipse and the orientation of its principal axis. At each proximal slice, the anterior/posterior and medial/lateral deviation of the center of the ellipse and the rotation of the principal axis are calculated relative to the pelvic reference. The root-mean-square error (RMSE) of the distance of the point cloud from the ellipse is defined to quantify fit and shape. Symmetry is calculated by dividing the point cloud along the minor axis of the ellipse and calculating the difference between the enclosed areas $R_{area} - L_{area}$.

to the point cloud of each slice within the defined volume. Finally, the software determined the fore/aft and medial/lateral deviation (in millimeter) of the origin of each ellipse as well as the orientation (in degrees) of the principal axis of each ellipse relative to the pelvic reference. The goodness of fit of each ellipse to its underlying point cloud was quantified as the root-mean-square deviation of the points to the ellipse. Right/left symmetry of each scan slice was determined by comparing the area encompassed by the right and left halves of the point cloud divided along the minor axis of the ellipse. The maximum deviation from the pelvic reference in each direction (fore/aft, medial/lateral, clockwise/counterclockwise, and right/left) of any slice within the defined volume was recorded as well as the range.

Each participant completed self-administered questionnaires on a computer. The SRS-22 contains 22 questions regarding self-perception of function/activity, pain, self-image/appearance, mental health, and satisfaction with management. Reliability, validity, and responsiveness of the SRS-22 have been extensively tested.[13–15] The SAQ includes 9 line drawings and 11 questions querying patient or parent perception of different aspects of appearance in 9 domains: general, curve, prominence, trunk shift, shoulders, waist, kyphosis, surgical scar, and chest. The SAQ shows excellent reliability, strong evidence of construct and concurrent validity, and better responsiveness than the appearance domain of the SRS-22.[16] The control group completed the SRS-22, but not the SAQ.

Discriminant validity was tested by assessing how scan measures differed between groups thought to differ in surface topography. Concurrent validity was demonstrated by evaluating correlations between scan measures and other measures of deformity, including radiological measures, optoelectronic assessment of posture, and measures of self-perception from the SRS-22 and SAQ.

Scanner accuracy was assessed using an aluminum tube with rectangular cross section of known dimensions (8 mm × 12 mm × 1.6 m) placed vertically within the scan volume. On 3 days, 2 sets of scans were collected in 5 positions within the scan volume. Sets of scans were taken, with the tube aligned parallel and rotated approximately 45° within the scan volume. At each position, the cross-sectional dimensions of the tube were measured from the scan at 4 different heights (0.75, 1.0, 1.25, and 1.50 m), corresponding to a clinically relevant range of torso height in adolescents.

Statistical analysis was performed using SPSS version 15.0 (SPSS Inc., Chicago, IL). Within-session reliability was examined using the intraclass correlation coefficient (ICC) of 3 repeated trials within the first test session of the scoliosis group and the control group. ICCs were computed for both a single rating and an average rating on the basis of 3 trials within a test session. Paired *t* tests and analysis of variance (ANOVA) were used to test difference in means for parametric data. Pearson correlation was used for linear comparisons of parametric data. Spearman ρ was used for nonparametric data. Statistical significance for all testing was established *a priori* at $P < 0.05$.

RESULTS

Accuracy

Average error in measuring the dimensions of the aluminum tube with rectangular cross section was 1.74 ± 1.56 mm, with root-mean-square error of 2.33 mm. There was no significant difference in measurement error due to day, test, height, or position (ANOVA, $P > 0.05$).

TABLE 2. Intraclass Correlation Coefficients (ICC) of 3-Dimensional Scan Measures Across Trials Within Session for the Control Group and the Preoperative Scoliosis Group Based on Repeated-Measures Analysis of Variance Using Single (ICC [3,1]) and Average (ICC [3,3]) Measures

	Control Group (n = 21)		Scoliosis Group (n = 36)	
	Single Measure	Average Measure	Single Measure	Average Measure
Maximum posterior shift	0.70	0.87	0.78	0.91
Maximum anterior shift	0.82	0.93	0.87	0.95
Anterior/posterior range	0.55	0.79	0.67	0.86
Maximum right shift	0.56	0.79	0.94	0.98
Maximum left shift	0.69	0.87	0.88	0.96
Right/left range	0.52	0.76	0.90	0.96
Maximum CCW rotation	0.83	0.94	0.96	0.99
Maximum CW rotation	0.50	0.75	0.97	0.99
Rotation range	0.72	0.88	0.97	0.99
Smallest residual	0.96	0.99	0.98	0.99
Largest residual	0.95	0.98	0.96	0.99
Residual range	0.86	0.95	0.94	0.98
Minimum right/left asymmetry	0.51	0.76	0.75	0.90
Maximum right/left asymmetry	0.39	0.66	0.63	0.84
Right/left asymmetry range	0.29	0.55	0.59	0.81
Mean	**0.66**	**0.83**	**0.85**	**0.94**
SD	**0.20**	**0.12**	**0.13**	**0.06**

CCW indicates counterclockwise; CW, clockwise.

Reliability

ICCs for individual (ICC [3,1]) and average scan measures (ICC [3,3]) are shown in Table 2. In the control group, the ICCs ranged from 0.29 to 0.96 for individual trials. An ICC of 0.75 is considered good and 5 of the 15 measures achieved this level of consistency. To improve reliability, we used the mean of 3 consecutive scans. The average measure ICC averaged 0.83, ranging from 0.55 to 0.99; 13 of the 15 measures achieved good reliability. In the preoperative scoliosis group, the average measure ICC averaged 0.94, ranging from 0.81 to 0.99; 15 of the 15 measures achieved good reliability. Further testing used the average of 3 consecutive scans.

Validity

Primary Cobb angle improved from 59.2° (SD, 13.8°) preoperatively to 21.2° (SD, 7.6°) postoperatively (paired *t* test, $P < 0.001$). Kyphosis magnitude decreased from 32.9° (SD, 16.0°) to 25.7° (SD, 9.5°) postoperatively (paired *t* test, $P = 0.016$). Shoulder height obliquity and rotation, measured with an optoelectronic measurement system, decreased after surgery (ANOVA, $P < 0.05$). The pain, appearance, management, and total scores for the SRS-22 improved after surgery and could not be differentiated from the control group postoperatively (ANOVA, $P < 0.05$). All 8 SAQ appearance domains improved after surgery (paired *t* test, $P < 0.001$). On the basis of these findings, there was sufficient evidence that quantitative and qualitative differences in torso asymmetry existed to compare with body scan measures for evaluation of between-group differences. Results are shown in Table 3.

Maximum medial/lateral shift and rotation relative to the pelvic reference, as well as maximum right/left area asymmetry, were able to differentiate among groups. Each measure decreased from preoperative to postoperative and approached the control value after surgery, demonstrating discriminant validity of the measures (ANOVA, $P < 0.05$).

Concurrent validity was examined by looking at the correlations between scan measures and radiological posture as well as responses to the SRS-22 and SAQ. Results are shown in Table 4. Correlations were classified as weak ($r = 0.0–0.2$), fair (0.2–0.4), moderate (0.4–0.6), good (0.6–0.8), or excellent (0.8–1.0).

Scan measures were moderately correlated with radiological measures. Maximum rotation was moderately correlated with largest Cobb angle ($r = 0.482$). Maximum posterior shift and anterior/posterior range were moderately correlated with kyphosis magnitude ($r = 0.508$ and 0.431, respectively).

TABLE 3. Differences Among the Preoperative, Postoperative, and Control Groups Are Shown for Radiological, SRS-22, SAQ, Postural Assessment Using an Optoelectronic System, and Surface Shape Measurement Using a 3-Dimensional Body Scanner*

Measure Type	Characteristic	Preoperative	Postoperative	Control	P
Radiological	N	36	36		
	Largest Cobb angle†	59.2 (13.8)	21.2 (7.6)		<0.001
	Kyphosis†	32.9 (16.0)	25.7 (9.5)		0.016
	Lordosis†	42.9 (13.6)	45.0 (14.3)		0.433
SRS-22 0 = worst 5 = best	N	34	32	17	
	Function‡	4.1 (0.6)	4.3 (0.5)	4.4 (0.4)	0.108
	Pain‡	3.9 (0.8)§‖	4.3 (0.7)§	4.6 (0.7) ‖	0.012
	Appearance‡	3.3 (0.6)§‖	4.4 (0.5)§	4.3 (0.5) ‖	<0.001
	Mental‡	3.8 (0.9)	4.2 (0.7)	3.9 (1.0)	0.179
	Management‡	3.6 (0.9)§	4.7 (0.6)§¶	4.0 (1.0)¶	<0.001
	Total‡	3.8 (0.5)§‖	4.4 (0.5)§	4.3 (0.5) ‖	<0.001
SAQ 0 = best 5 = worst	N	18	29		
	General†	4.0 (0.5)	2.7 (0.9)		<0.001
	Curve†	3.2 (0.9)	1.3 (0.5)		<0.001
	Prominence†	2.5 (0.9)	1.3 (0.5)		<0.001
	Trunk shift†	2.8 (1.1)	1.3 (0.5)		<0.001
	Waist†	3.7 (1.3)	1.5 (1.0)		<0.001
	Shoulders†	3.4 (0.9)	1.6 (0.8)		<0.001
	Kyphosis†	2.6 (1.1)	1.2 (0.4)		<0.001
	Chest†	3.4 (1.6)	1.7 (1.0)		<0.001
Posture	N	36	35	20	
	Shoulder height obliquity‡	0.5(3.1)§	−2.3 (6.2)§¶	0.6 (1.5)¶	0.012
	Shoulder rotation‡	−6.6 (6.6)§‖	−1.8 (9.6)§	−0.6 (3.3)‖	0.006
Torso shape	N	36	36	21	
	Anterior/posterior shift‡	22.7 (7.4)	24.3 (7.2)	27.0 (9.0)	0.136
	Medial/lateral shift‡	21.7 (11.5)§‖	13.6 (5.3)§¶	8.4 (4.7)‖¶	<0.001
	Torso rotation‡	18.9 (7.2)§‖	12.3 (3.9)§¶	6.8 (3.0)‖¶	<0.001
	Maximum ellipse misfit‡	49.5 (21.3)	51.4 (22.2)	41.9 (21.8)	0.115
	Right/left asymmetry‡	9.2 (2.3)§‖	7.9 (1.5)§¶	6.3 (0.8)‖¶	<0.001

*Measurement types for which control data were available were assessed using analysis of variance, otherwise paired Student t tests were used. Main effects are shown in the “P” column, and least significant difference post hoc testing is indicated with symbols for $P < 0.05$.

†Comparison by analysis of variance.

‡Comparison by paired t test.

§Post hoc testing, preoperative versus postoperative, $P < 0.05$.

‖Post hoc testing, preoperative versus control, $P < 0.05$.

¶Post hoc testing, postoperative versus control, $P < 0.05$.

SRS indicates Scoliosis Research Society; SAQ, Spinal Appearance Questionnaire.

TABLE 4. Correlations Between Scan Measures and Other Measures of Deformity, Including Radiological Measures, Optoelectronic Assessment of Posture, and Measures of Self-Perception From the SRS-22 and the SAQ

Measure Type	Measure	Scanner Measure	Correlation	*P*
Radiological measures	Largest Cobb angle	Rotation range	0.482	0.003
	Kyphosis magnitude	Posterior shift	−0.508	0.004
	Kyphosis magnitude	Anterior/posterior range	0.431	0.017
	Lordosis magnitude	Smallest residual	0.449	0.015
	Lordosis magnitude	Largest residual	0.436	0.018
	Largest Cobb angle	Objective index	−0.477	0.003
Optoelectronical measure	Shoulder obliquity	Maximum right shift	0.704	<0.001
	COPL symmetry—pelvis		0.456	0.005
	Shoulder obliquity	Maximum left shift	0.750	<0.001
	Shoulder rotation		−0.382	0.022
	COPL symmetry—shoulder		−0.348	0.037
	COPL symmetry—pelvis	Right/left range	−0.364	0.029
	Shoulder obliquity	Maximum CW rotation	−0.484	0.003
	COPL symmetry—pelvis		−0.406	0.014
	Shoulder obliquity	Maximum CCW rotation	−0.465	0.004
	Shoulder rotation		0.504	0.002
	Axial tilt with respect to pelvis		0.333	0.047
	Axial rotation with respect to pelvis		−0.460	0.005
	Axial tilt	Minimum area difference	0.557	<0.001
	Axial tilt	Maximum area difference	0.496	0.002
	COPL symmetry—pelvis		−0.376	0.024
SRS-22 domain	Management	Maximum CW rotation	−0.386	0.024
	Function	Maximum CCW rotation	0.346	0.045
	Mental		0.544	0.001
	Management	Anterior/posterior range	−0.421	0.013
	Mental	Maximum right shift	−0.403	0.018
	Mental	Maximum left shift	−0.641	<0.001
	Total		−0.463	0.006
SAQ domain	Curve	Maximum left shift	−0.554	0.017
	Kyphosis		−0.550	0.018
	Shoulders	Maximum right shift	−0.528	0.024
	Kyphosis		−0.479	0.044
	Curve	Maximum CCW rotation	0.497	0.036
	Curve	Maximum CW rotation	0.672	0.002
	Prominence		0.477	0.046
	Trunk shift		0.592	0.010
	Shoulders		0.554	0.017
	Curve	Rotation range	0.485	0.041
	Trunk shift		0.631	0.005
	Prominence	Smallest residual	0.507	0.032

CCW indicates counterclockwise; CW, clockwise; COPL, center of pressure line; SRS, Scoliosis Research Society; SAQ, Spinal Appearance Questionnaire.

Scan measures showed moderate-to-good correlations with measures of posture. Maximum lateral shift had good correlation with shoulder height obliquity (r = 0.750) and moderate correlation with symmetry of the center of pressure line within the pelvis (r = 0.456). Maximum rotation was moderately correlated with shoulder rotation (r = 0.504), shoulder height obliquity (r = 0.484), and symmetry of the center of pressure line within the pelvis (r = 0.406).

Scan measures showed fair-to-moderate correlations with responses to the SRS-22. Maximum rotation had fair correlation with the function (r = 0.346) and management (r = 0.386) domains and moderate correlation with the mental (r = 0.544) domain of the SRS-22. Maximum lateral shift had moderate correlation with total (r = 0.463) and good correlation with mental (r = 0.641) domains of the SRS-22.

Scan measures showed moderate and good correlation with responses to the SAQ. Maximum lateral shift showed moderate correlation with the curve (r = 0.554), kyphosis (r = 0.550), and shoulders (r = 0.528) domains. Maximum rotation showed moderate correlation with the prominence (r = 0.477), trunk shift (r = 0.592), and shoulders (r = 0.554) domains and good correlation with the curve (r = 0.672) domain. Range of rotation showed moderate correlation with the curve (r = 0.485) domain and good correlation with the trunk shift (r = 0.631) domain. Misfit of the ellipse with the underlying point cloud had moderate correlation with the prominence domain (r = 0.507).

DISCUSSION

Results of this study demonstrate the accuracy, reliability, and validity of the Vitronic 3D scanner for measuring torso shape in IS. With an average error of 1.74 mm, accuracy is equivalent to reports for other scanners[17] and meets the 2-mm threshold recommended[18] for monitoring changes in torso shape in scoliosis. We created clinically relevant indices of torso asymmetry similar to others in the literature.[11,19,20] The indices directly measure offsets and angles relative to an independent, body-based reference and differentiate between normal and pathological as recommended by Patias *et al*.[11]

This study improves upon previous work. Dawson *et al*[19] quantified anterior/posterior and medial/lateral deviation of the center of an ellipse defined at 10 cross-sectional levels, using a circumferential scanning system. Vertical resolution limited its ability to image very tall or short patients. Jaremko *et al*[20] refined this methodology, using a higher resolution scanner, and introduced additional measures. They computed indices relative to a pelvic reference describing principal axis rotation, anterior/posterior and medial/lateral deviation, back surface rotation, and half and quarter area differences defined by lines parallel and perpendicular to the principal axis passing through the centroid. We adapted versions of these indices but applied them for a different goal.

The goal of previous studies was to reliably predict Cobb angle from surface measurements. Using stepwise linear regression, Jaremko *et al*[20] correctly estimated 65% of Cobb angles within 5°, using measures of rib hump, lateral deviation, left-right area asymmetry, and torso rotation. Similarly, using angular and distance-based scan indices, Goldberg *et al*[21] found significant correlations between Cobb angle and topographical measures. Neither study examined the relationship of spinal deformity with appearance or quality of life.

The relationships of spinal deformity with measures of appearance and quality of life have been assessed in few previous studies. Trunk appearance, shoulder-height difference, shoulder-angle symmetry, decompensation, scapula asymmetry, waist crease, waist asymmetry, and pelvic asymmetry predicted 85% of the cosmetic deformity noted in photographs of 20 patients with IS by 8 judges ranging in background and experience with scoliosis.[6] This study was based on rater judgment, not on standardized quantitative assessment. Using back surface topography, upper thoracic transverse plane trunk deformity had a moderate-inverse relationship ($r = -0.36$), with perception of self-image for preoperative IS patients.[22] This study, however, considered only back surface, not the entire circumference of the torso. This study adds to the literature by relating indices derived from a 360° circumferential assessment of trunk deformity to measures of appearance and quality of life.

Within-day reliability of scan measures has been previously examined by few studies. Pazos *et al*[23] evaluated within-day reliability of torso shape measurement, using the Inspeck system (Inspeck Inc., Montreal, Quebec, Canada). They found similar levels of error and reliability to those reported here, with ICCs ranging from 0.91 to 0.99.

There is no consensus on which surface topography parameters best detect progression of scoliosis.[24] Parent *et al*[24] analyzed responsiveness of commonly used measures of change in torso shape for 58 adolescents with IS receiving conservative management whose Cobb angle had progressed at least 5° in the past year. The most sensitive measures were decompensation, trunk rotation, and lordosis angle, demonstrating a standardized response mean greater than 0.8, significantly better than the standardized response mean for primary Cobb angle. This study supports these findings; lateral shift (decompensation) and rotation relative to the pelvic reference showed significant postoperative differences.

We did not attempt to predict Cobb angle, using scan measures. Previous work has shown that radiographical and physical measures of deformity do not correlate well with patient or parent perception of appearance, or with the cosmetic outcome of scoliosis surgery.[2] Stokes[25] and others have asserted that estimation of Cobb angle from scan measures is inappropriate. The internal structure of the deformity (individual vertebral rotation) is mitigated by the ribs and soft tissue before being translated into surface topographic changes. Our goal and anticipated future clinical application of this technology are to relate surface topographical measures to perception of appearance.

There are limitations to this study. Accuracy was assessed using an aluminum tube with rectangular cross section. A shape and volume more closely resembling a human torso may have been more directly relevant. Further testing on a torso model as well as other geometric shapes resulted in consistent accuracy estimates of 1.5 to 1.7 mm, independent of the shape or dimension measured.

Our sample size was relatively small, but was consistent with validation studies of similar systems.[17,20] The preoperative scoliosis group was diverse, including males (28%) and females (72%), as well as those with juvenile (25%) and adolescent (75%) onset of scoliosis. This study was not specifically designed to evaluate differences due to sex, age, or onset of scoliosis. This diversity adds to the generalizability of study findings. Subgroup analysis based on demographic, severity, and curve-type characteristics will be performed with a larger sample guided by a formal power analysis.

The control group was concurrent but not age, sex, or size matched to the patient population. The scoliosis population analyzed was selected through ongoing prospective recruitment of a large number of patients with scoliosis at our facility. Those included represent the first who reached follow-up of 2 years after spinal instrumentation and fusion. The age and size composition of the surgical group were unknown when the control group was initially recruited.

The control group did not respond to the SAQ. Sanders *et al*[16] reported that half of adolescents without scoliosis find "something wrong" with their appearance when they think they might have scoliosis but actually do not. Collecting the SAQ on the control group may have improved the study design and allowed a better analysis of comparative change in the scoliosis group.

Within-session reliability was evaluated for the control group. Stability of measures of shape over time in a population expected to change only as the result of growth was not tested. It is possible that some of the changes noted between the pre- and postoperative group could have resulted from growth and not necessarily surgery.

In conclusion, our study demonstrates the accuracy, reliability, and validity of the Vitronic 3D scanner for measuring torso shape. The system is sufficient to prospectively monitor changes in torso shape due to scoliosis and other chest wall deformities. Within-day reliability is excellent. Scan measures differentiate between normal and pathological and between preoperative and postoperative torso shape and show good to moderate correlation with measures of appearance and quality of life. Future work will prospectively examine the impact of instrumentation strategy on torso shape on the basis of curve type and the resulting impact on measures of appearance and quality of life.

➢ Key Points

- ❑ Surface topography is an attractive noninvasive alternative to radiography for quantifying body shape and patient perception of appearance, but has not been studied in the context of patient-centered outcomes.
- ❑ The aim of this study was to establish the accuracy, reliability, and validity of the Vitronic 3D Body Scanner for the evaluation of torso deformity in patients with IS.
- ❑ Scanner-based indices differentiate between normal and pathological and between preoperative and postoperative body shape and show good correlation with measures of appearance and quality of life.

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