Assessment of Spinal Deformity and Scoliosis with a Novel Automated Artificial Intelligence Powered Workflow Generates a Highly Reliable Suite of Whole-Body Surface Topographic Measurements

Benjamin Newcomb Groisser[1], Howard J Hillstrom[2], Ankush Thakur[3], Kyle Morse, Matthew E Cunningham[4], Michael Timothy Hresko[5], Ron Kimmel, Alon Wolf, Roger F Widmann[6]
[1]Technion, [2]Hospital For Special Surgery, [3]Pediatric Orthopedics, Hospital For Special Surgery, [4]Hosp for Special Surg-Cornell, [5]Boston Children's Hospital, [6]Hosp for Special Surgery

INTRODUCTION: Adolescent Idiopathic scoliosis (AIS) is a complex 3-dimensional malalignment of the spine that presents itself to patients in several externally visible characteristics including waist crease asymmetry, uneven shoulder height and chest wall asymmetry. While standing radiographs serve as the gold standard for diagnosing AIS, it exposes patients to radiation and fails to measure these important characteristics. Surface topography enables the objective quantification of these externally visible characteristics, which may better reflect what patients care about most in their treatment. Previous studies of surface topography have demonstrated high reliability of certain topographic measurements; however, these systems are hampered by requiring manual landmarking, being limited to torso only scans, and requiring elaborate protocols with long scan times. In this study, we utilize a thirty camera system to take full body 3D topographic scans in several poses. Each scan takes 1.8 milliseconds, effectively eliminating motion artifacts older systems are susceptible to. These 3D scans were then processed using an automated artificial intelligence powered pipeline to obtain topographic measurements without the inconsistencies and subjectivity of manual measurements or landmarking. In this study we investigate the reliability of automated topographic measurements on spinal deformity patients and controls.

METHODS: Individuals with spinal deformity and healthy controls were recruited to participate in this IRB approved study. Informed consent and assent were obtained. Subjects were scanned using a thirty camera surface topography system by two investigators three times each in several poses. The first scan was immediately followed by the second scan to assess test-retest reliability for each pose. The third scan for each pose was completed after repositioning the subject to test remove-replace reliability. The following clinically relevant poses were selected for analysis: fingers on clavicles, A-pose, and Adam's forward bend. An automated pipeline computed several 3D measurements which were categorized as intrinsic or pose-dependent. Intrinsic measurements are constant under rigid transformations, while pose-dependent measurements are sensitive to orientation or postural changes. Intrinsic measurements computed were spine length, back area, cross-sectional area, and section volume. Pose-dependent measurements computed were angle of trunk rotation, centroid deviation, maximum trunk axis, and Q Angle. Intraclass correlation coefficients were computed for each pose and measurement. Surface reconstruction accuracy was measured by scanning an optical breadboard calibration target with evenly spaced fiducial markers. A plane was fit to the 3D surface and accuracy was measured between the calibration target and the plane (point-to-plane) as well as between individual landmarks.

RESULTS: Forty-six subjects participated in this study including 26 scoliosis patients (14 female, 12 male) with a mean age of 14.7 (+/- 5.2) years and BMI 21.17 (+/- 9.02) kg/m2 and 20 controls (9 female, 11 male) with mean age of 14.6 (+/- 4.6) years and BMI of 21.73 (+/- 7.60) kg/m2. Patients' Cobb angles ranged from 15°-83° with an average of 48.0° (+/- 40.46°), as measured by 3D radiographic reconstructions. Surface reconstructions of the calibration target were highly accurate with 0.2 mm planar reconstruction RMS error and 1.4 mm absolute landmarking RMS error. Intrarater reliability and interrater reliability of all surface topographic measurements were highly reliable with 80% of all ICC values ≥ 0.90. Reliability of intrinsic measurements was nearly perfect with an average interrater ICC of 0.99, while pose-dependent measurements had more variability in reliability with an average ICC of 0.86. Mean ICC values for intrarater and interrater reliability of intrinsic and pose-dependent measurements across all poses and measurements are tabulated in Table 1.

DISCUSSION AND CONCLUSION: The surface topographic scanner and automated analysis pipeline demonstrated high reliability in measuring surface characteristics of spinal deformity. As expected, intrinsic measurements were particularly reliable, as these measurements are independent of the patient's posture which can be a significant source of variability. Pose-dependent measurements were also reliable, but increased attention to the scanning protocol and more strictly standardizing patient posture may improve this further. This system is capable of reliably and objectively quantifying 3D surface characteristics of spinal deformity in an automated fashion. This system may be highly valuable in screening and assessment of scoliosis, improving patient expectations of surgery, and assessment of patient reported outcome measures.

Measurement Type	ICC for Intra-Rater A		ICC for Intra-Rater B		ICC for Inter-Rater
	Test-Retest	Remove-Replace	Test-Retest	Remove-Replace	Rater A-Rater B
Intrinsic	0.99	0.99	0.99	0.99	0.99
Pose-Dependent	0.88	0.86	0.90	0.85	0.83