Turk Neurosurg 33(2):252-257, 2023

Original Investigation

Received: 27.01.2022
Accepted: 07.06.2022

DOI: 10.5137/1019-5149.JTN.38065-22.2

Published Online: 04.01.2023

Statistical Shape Analyses of Pediatric Patients with Scoliosis After Surgical Correction

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ABSTRACT

AIM: To investigate the preoperative and postoperative differences in the upper-body and spinal shapes of patients with scoliosis.

MATERIAL and METHODS: Digitized two-dimensional X-ray images were used to obtain the shapes of the upper-body and spine. The preoperative and postoperative mean shapes were compared by using a Generalized Procrustes analysis. The thin plate spline (TPS) method was used to evaluate the spinal shape deformation between the preoperative and postoperative periods.

RESULTS: The pre- and postoperative upper-body and spinal shape differences were significant. The TPS graphics showed high-level deformations between the pre- and postoperative periods. The left superior border of the L4 spinous process showed the highest deformation.

CONCLUSION: The preoperative and postoperative upper-body and spinal shape differences and structural deformations that correlated with scoliosis were shown to be significant.

KEYWORDS: Cobb angle, Statistical shape analysis, Scoliosis, Pediatric

ABBREVIATIONS: PCA: Principal component analysis, **TPS:** Thin Plate Spline

INTRODUCTION

Approximately 100 years ago, Cobb wrote, "Scoliosis is always a problem that is interesting and difficult to solve," and despite the evolving surgical techniques and technology, scoliosis remains difficult to correct. Scoliosis was first described by Galen (131–201 AD) as kyphosis, lordosis, and scoliosis (6,10). The condition in which coronal curves shown on anteroposterior direct radiography are >10° is called scoliosis (2), which is caused by rotation of the spine about its axis. The condition is the most common deformity of the spine and presents as a complex curve that causes deformity not only in the coronal plane but in all three planes. Approximately 80% of structural coronal deformities are classified as idiopathic scoliosis that can begin at any time during the growth period (7).

The incidence of coronal curves ≥ 10° varies between 1% and 3%, whereas the incidence of curves that require treatment ranges from 0.15% to 0.3% (8). The etiology can involve genetic and hormonal causes, biomechanical causes, neurological dysfunction, and connective tissue anomalies. All of these causes are interrelated and affect each other (9). There is a broad spectrum of treatments ranging from follow-up, exercise to wearing a corset after fused or non-fused surgery. The Cobb angle and age are the most critical determinants of the treatment plan (17).

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Advancements in imaging technology and software have made it possible to analyze the form of an organ or structure using key points of anatomical significance. The coordinates of these points, called landmarks, are obtained from digital images of the organ or bony structure and make it easier to study the geometric shape of a structure of interest. Statistical shape analysis is a modern geometric morphometric analysis that evaluates changes in the shape of a structure of interest caused by demographic factors, environmental influences, or diseases (12). Recently, the number of studies using statistical shape analysis in both medical science and neurosurgery has been increasing (11,13-15,19), and has contributed to the use of statistical shape analysis as a supporting tool in the data visualization, analysis, and interpretation stages.

This study aimed to investigate the preoperative and postoperative differences in the upper-body and vertebral shapes of patients with scoliosis using a landmark-based geometrical morphometric method for the first time.

MATERIAL and METHODS

Subjects

We performed X-ray imaging of 22 (9 males, 13 females) patients with scoliosis aged between 10 and 18 (mean ± standard deviation: 14.09 ± 2.09) years. The X-ray images of the patients admitted to the Bursa Uludag University Faculty of Medicine Department of Neurosurgery and Department of Orthopedics and Traumatology between April 2017 and August 2019 were retrospectively reviewed. All X-ray imaging examinations were performed on a Samsung XGEO GF50 floor-mounted digital X-ray instrument. All of the patients underwent surgery in the Department of Neurosurgery and Department of Orthopedics and Traumatology at Bursa Uludag University. The study protocol was approved by the local Ethics Committee (No. 2019-21/14) of Bursa Uludag University Medical School, and the informed consent forms were signed by the wardens of the participants.

Collection of Two-Dimensional Spinal Landmarks

A statistical shape analysis using homologous anatomical landmarks was performed. For both the spine and upper-body, 10 landmarks (Table I) markings were made on preoperative and postoperative scoliosis X-ray images (Figures 1A, B). TPSDIG 2.04 software was used to collect the upper-body and spinal data.

Geometric Morphometric Analysis

The Generalized Procrustes analysis was used to obtain the minimum sum of squares differences between landmarks for the pre- and postoperative mean upper-body and spinal shapes and related tangent coordinates (3). Tangent coordinates derived from the Procrustes analysis were used in the principal component analysis (PCA). PC scores obtained from PCA were used to perform the paired Hotelling T^2 test, which was used to compare the mean upper-body and spinal shapes obtained by Procrustes analysis during the pre- and postoperative periods. The thin plate spline (TPS) method was used to compare the shape deformation of the spine between the pre- and postoperative periods. The points exhibiting the greatest enlargements or reductions in the TPS analysis were labeled as deformations.

Table I: Definitions of Landmarks Used in the Present Study

Landmark	Upper body	Spine
Landmark 1	C7 spinous process	C7
Landmark 2	The acromial angle of right scapulae	T2
Landmark 3	The superior angle of right scapulae	T4
Landmark 4	The inferior angle of right scapulae	T6
Landmark 5	The superior border of right iliac	T8
Landmark 6	L4 spinous process	T10
Landmark 7	The superior border of left iliac	T12
Landmark 8	The inferior angle of left scapulae	L2
Landmark 9	The superior angle of left scapulae	L4
Landmark 10	The acromial angle of left scapulae	S1

Landmark Reliability

We calculated the intra-rater reliability coefficient for a two-facet crossed design (landmark pairs by rater and by subject) based on the generalizability theory (4). Landmarks were marked by an investigator. The same investigator re-marked the same landmarks on all images again after 1 month. The G coefficient was 0.964, indicating good repeatability, so we continued further analyses. Landmark reliability calculations were performed according to the following link: (http://biostat.home.uludag.edu.tr/landmark_reliability/G_coefficient.html) (4).

General Statistical Analysis

The Wilcoxon signed-rank test was used to compare the pre- and postoperative angles between terms. R 3.5.1 (20), PAST 3.0 (5), and SPSS (18) software applications were used for statistical analysis in this study.

RESULTS

The pre- and postoperative landmark markings were used to obtain the upper-body and spinal Procrustes mean shapes (Figure 2). There was a significant difference between the pre- (p=0.027) and postoperative shapes (p=0.019). The TPS graphic shows the high-level deformations of the upper-body shapes that occurred between the pre- and postoperative periods (Figure 3). In general, compared with the preoperative images, the postoperative images showed that an extension was present in the area surrounded by landmarks 6 (L4 spinous process) and 7 (superior border of the left iliac), despite a contraction in the upper-body shape. However, the regions with the highest contraction were the areas surrounded by landmarks 1, 3, 4, 5, 6, and 9.

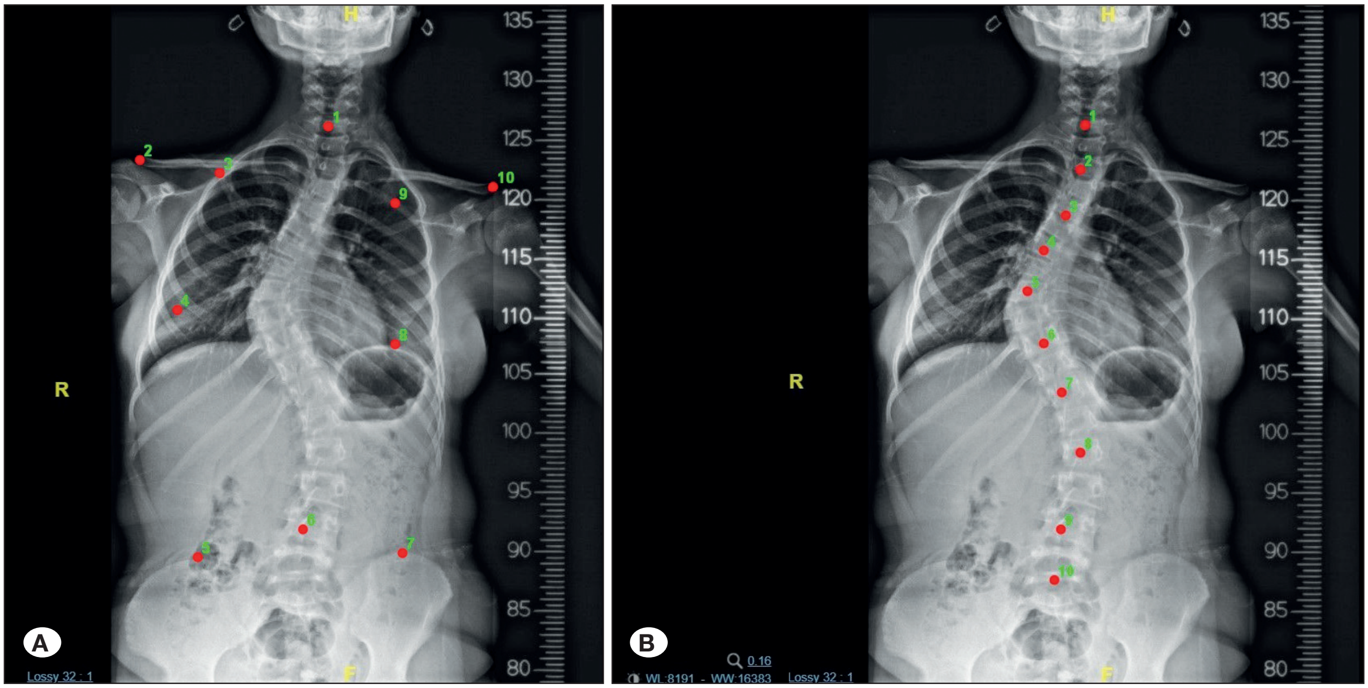

Figure 1: Landmark markings on the upper-body **(A)** and spine **(B)**.

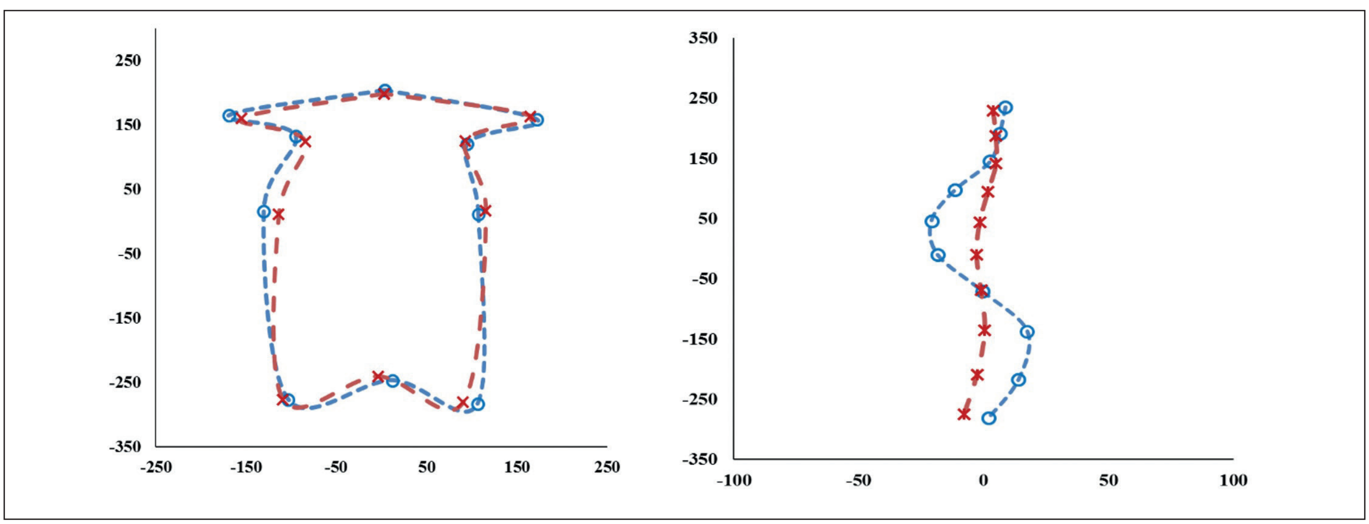

Figure 2: Procrustes mean shapes in the pre- and postoperative spinal and upper-body images of pediatric patients with scoliosis (o: Preoperative and x: Postoperative).

The high-level of deformations of the spine that occurred from the pre- to postoperative periods are shown in the TPS graphic (Figure 4). In the postoperative period, a deformation was observed in the spinal column not seen in the preoperative period as expected, and this deformation appeared as a narrowing. The regions with the highest contraction were surrounded by landmarks 3, 4, and 5 and landmarks 9 and 10.

In this study, 24 Cobb angle measurements, 22 T1 tilt-angle measurements, and 22 L5 coronal tilt-angle measurements were obtained from 22 patients in the pre- and postoperative periods. After treatment, angle measurements obtained from each region showed a statistically significant decrease relative to those in the preoperative period. The results of the related analyses are presented in Table II.

DISCUSSION

Surgery treatment is recommended for scoliosis patients to stop the curve progression. Several different methods were used to measure changes in the spine before and after surgery, such as the Cobb angle, rib-vertebral angle difference, T1 tilt, and L5 coronal tilt angles (16). We performed a landmark-based geometric morphometric approach to show the upper-

Table II: Change of Cobb, T1 Tilt and L5 Coronal Tilt Angle Measurements

	Cobb	T1 tilt	L5 coronal tilt
Pre-operative	44° (11°-72°)	7.50° (2.80°-27.10°)	6.50° (2.40°-24.10°)
Post-operative	14° (0°-43°)	3.80° (1.10°-18.80°)	2.25° (1.10°-11.60°)
Decresing amount	70% (4.44-100)	55.36% (5.56-88.99)	67.23% (0-89.08)
p	**<0.001**	**<0.001**	**<0.001**

Angel measures and decreasing amount presented as median(minimum-maximum).

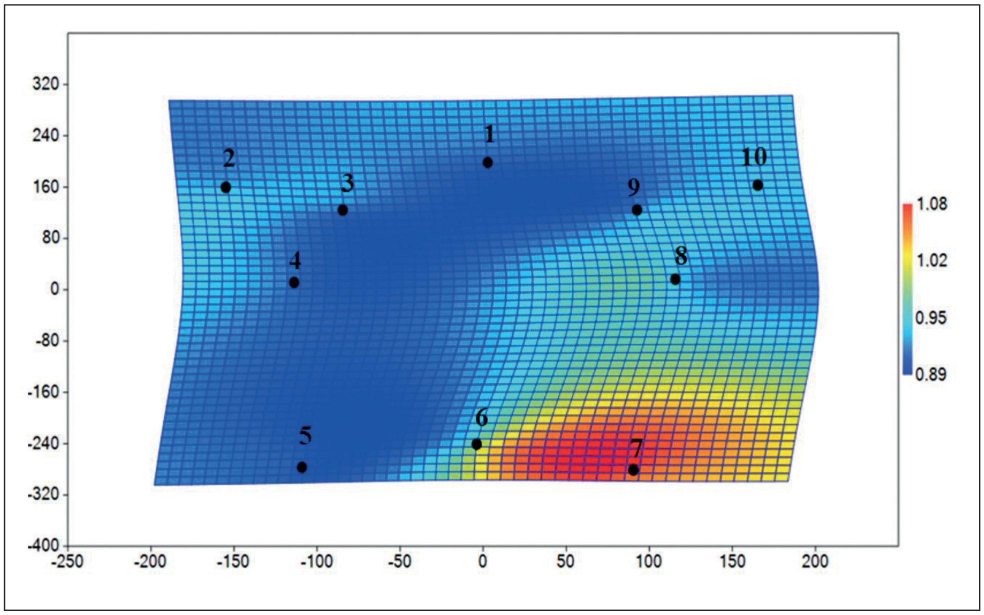

Figure 3: A thin plate spline demonstrating the differences in the mean upper-body shape deformations between the pre- and postoperative periods.

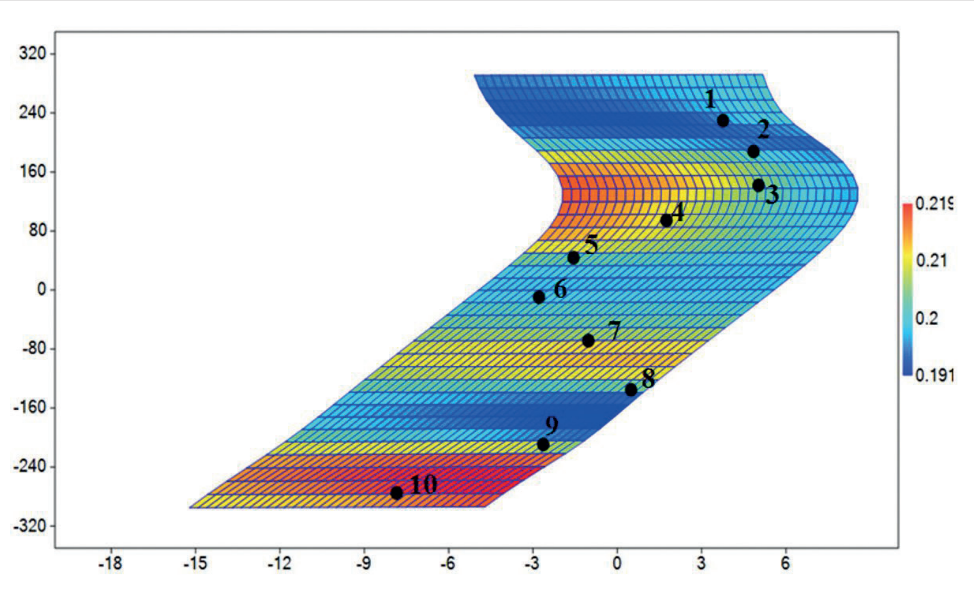

Figure 4: A thin plate spline demonstrating the differences in the mean spinal shape deformations between the pre- and postoperative periods.

body and spinal changes in the pre- and postoperative periods in the patients with scoliosis. In addition to the general changes, changes on a regional basis were also observed.

The success of the operation can be determined by the changes in several angles or measurements, as shown by previous studies, but to the best of our knowledge, our study is the first to use statistical shape analysis to predict the success of the scoliosis operation. We analyzed the shape of the upper-body and spine in scoliosis patients. We observed significant differences in the mean upper-body and spinal shapes between the pre- and postoperative periods.

Deformation was determined according to the postoperative period shapes relative to the preoperative period shapes. Deformation of the upper-body is generally detected as contraction. However, the most prominent deformation observed as contraction was in the area delimited by landmarks 1, 3, 4, 5, 6, and 9 in the postoperative period. In general, although upper-body narrowing was detected, extension was observed in the area surrounded by landmarks of the inferior angle of the right scapulae and inferior angle of the left scapulae relative to the preoperative shape. These data showed that the most remarkable improvement was at the extreme point of the deformation, which indicated a successful operation.

As expected, the change observed in the spine between the pre- and postoperative periods was in the contraction direction. The regions with the highest contraction were those surrounded by landmarks 3, 4, and 5 and landmarks 9 and 10. The reason for this is that most of the patients had a double curvature.

In most of the series in the literature, the success of an operation was evaluated by the correction of the Cobb angle, T1 tilt-angle, and L5 coronal tilt angle (1, 2). In our series, the Cobb angle, T1 tilt-angle, and L5 coronal tilt-angle measurements showed a statistically significant decrease between the pre- and postoperative periods, indicating successful operations, as also shown by the statistical shape analytical results.

This study showed the structural deformations of the upper-body and spine that were caused by scoliosis. Our study results are consistent with those of previous studies. However, our results and those of previous studies also show that additional studies using more controls and types of patients with scoliosis are needed to understand this pathology so that new treatment strategies can be developed. The main limitation of this study was the relatively small number of patients.

CONCLUSION

We observed significant shape deformations in the spine and upper-body in patients with scoliosis between the pre- and postoperative periods. To the best of our knowledge, this is the first study using a landmark-based geometrical morphometric method to compare the pre- and postoperative upper-body and spinal shapes of patients with scoliosis by considering the topographic distribution of these structures. We hope that the results demonstrating localized variations in scoliosis components that constitute the overall shape of the spine can be used to guide future clinical studies in scoliosis surgery.

ACKNOWLEDGEMENTS

Preparation for publication of this article is partly supported by Turkish Neurosurgical Society.

AUTHORSHIP CONTRIBUTION

Study conception and design: GO, MOT
Data collection: MOT, ISK, BA, SD
Analysis and interpretation of results: GO
Draft manuscript preparation: GO, MOT
Critical revision of the article: MOT, SD
Other (study supervision, fundings, materials, etc...): ISK, BA, SD
All authors (GO, MOT, ISK, BA, SD) reviewed the results and approved the final version of the manuscript.

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