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Evaluation of Reducibility of Trunk Asymmetry in Lateral Bending

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Abstract. The value of the lateral bending test is important in the assessment of spinal curve mobility and prediction of surgical outcome in the treatment of adolescent idiopathic scoliosis (AIS). However, radiographic bending tests are unable to assess the reducibility of trunk asymmetry. This study aims to exploit surface topography measurement in order to evaluate the changes in shape of the trunk **(a)** between bending and neutral standing positions, and **(b)** between standing pre- and post-operative visits, in a cohort of adolescents with AIS having undergone surgical correction; and to correlate the differences measured in cases (a) and (b). Our cohort includes 13 patients with right thoracic AIS. Each patient had their 3D trunk surface digitized with a multi-head InSpeck system in standing posture (at the pre-op and post-op visits) and in maximum voluntary right and left bending (at the pre-op visit). We developed a novel trunk shape analysis method which produces a set of inclined trunk cross-sections allowing comparison between different postures. Two asymmetry indices, trunk rotation (TR) and back surface rotation (BSR), were computed in all cases and a statistical analysis was performed. Our correlation study (Pearson test) showed fair correlations in most cases between the changes in side-bending and those post-surgery, with the strongest relationship (p-value < 0.01) when combining the TR measurements from both bendings. These results provide evidence that the bending test can be used to assess trunk asymmetry reducibility. The proposed approach could provide a non-invasive trunk asymmetry reducibility test for routine clinical use in AIS surgery planning.

Introduction

The value of the radiographic lateral bending test is important in the assessment of spinal curve mobility, surgery planning and prediction of surgical outcome in the treatment of adolescent idiopathic scoliosis (AIS). However, radiographic bending tests are unable to assess the reducibility of trunk asymmetry, even though external trunk asymmetry is of primary concern to the patients [1-2].

To address this gap, several different systems have been used to acquire the surface shape of the back or whole trunk of scoliotic patients, and in that context, indices to quantify asymmetry, both locally in terms of measures from surface cross-sections and globally in terms of measures from surface regions, have been developed [1, 3-8]. Our research team has for several years utilized non-invasive surface topography to acquire the whole trunk of patients at the Sainte-Justine Hospital scoliosis clinic [9]. Several trunk shape indices have been developed and their reliability evaluated on patients in standing position [10]. We have also proposed an adaptation of the trunk analysis method to the lateral bending position, thus allowing comparison between postures [11].

The present work aims to propose an original method to evaluate the reducibility of trunk asymmetry in subjects with AIS, using two trunk asymmetry indices computed from inclined sections extracted from trunk surfaces using non-invasive surface topography. We used this method on a cohort of adolescents with AIS who are candidates for posterior surgical correction. The changes in values of the two indices are evaluated for all patients (a) between bending and neutral standing positions, and (b) between standing pre- and post-operative visits, to investigate the correlations between the differences measured in cases (a) and (b), with the long-term aim of using this method in AIS surgery planning.

1. Materials and Methods

1.1. Trunk Surface Acquisition

Our cohort comprised 13 AIS patients with right thoracic major spinal curves (with or without lumbar thoracolumbar/lumbar secondary curves; Lenke types 1, 2 and 3). When visiting the scoliosis clinic for their preoperative evaluation, each patient had their 3D trunk surface geometry acquired with a multi-head optical digitizing system (InSpeck Inc.) in standing posture (with arms in slight abduction by the side) and in maximum voluntary right and left side-bending. The same patients also had their trunk surface digitized at their post-operative follow-up visit. Prior to surface acquisition, visible markers were placed on the patient's skin, indicating: left and right antero-superior iliac spines (ASIS), spinous processes of the prominent vertebra, T1, apex and limit vertebrae, and several other landmarks on the pelvis and rib cage. The result of each acquisition (followed by processing steps, registering and merging of the partial trunk surfaces) is a complete, textured surface mesh of the trunk. A previous study of this system demonstrated an accuracy of about 1.4 mm [9].

1.2. Cross-sections Extraction

For each reconstructed trunk, we first define a patient reference frame as follows: the origin is located on the patient's back at the pelvic level, specifically at the midpoint of the two posterior-superior iliac spines (PSIS). The X axis points to the right of patient; its direction is given by the line passing through the two ASIS, projected on the horizontal plane. The Z axis points toward the back and the Y axis points upward.

We then define three guiding curves, one along the back and two along the front (left and right sides) of the 3D trunk surface. For the back guiding curve, four control points were defined along the back valley: at the midpoint of the two PSIS, at the waist level, at the midpoint between the waist and the vertebra prominens and at the vertebra prominens. For each of the two front guiding curves, four control points were defined as follows: on the ASIS, at the waist level, on the nipple and on the medial extremity of the clavicle. Each guiding curve is represented as a cubic interpolation spline with parameter values at the control points [0 1/3 2/3 1] from bottom to top.

We then sample the three curves uniformly at n = 100 points, yielding, at each level, three points defining a cutting plane. The intersection between each of the n cutting planes and the polygonal surface mesh is a set of points that constitute a cross-section. However, we wish to obtain fairly smooth, uniformly spaced and ordered sets of points forming closed contours. To achieve this, implicit modeling with Radial Basis

Functions (RBF) is used [12]. Then, for each cross-section, we evaluated the coordinates of 200 uniformly distributed points to represent the contour.

In order to analyze the cross-sections and compute indices on them, it is necessary to establish a local reference frame for each section. Our approach consists in a principal component analysis on the 3D positions of the points to extract the major and minor axes, which define respectively the X and Z axes of the section's local reference system, the Y axis being normal to the other two and pointing upward. The origin is located at the centroid. Figure 1 illustrates the whole process of cross-section extraction.

1.3. Indices Measurement

Trunk shape was assessed by computing the following cross-sectional measurements, based on previous studies of scoliotic external asymmetry [1, 4-8, 10]:

- **Trunk Rotation (TR):** angle between the horizontal projection of the section's local X-axis and the patient X-axis; this angle is *signed*, with positive angles for clockwise rotation around Y and negative angles otherwise.
- **Back Surface Rotation (BSR):** angle between the dual-tangent to the back profile and the local X-axis, measured in the plane of the section; this angle is *signed*, with the sign having the same meaning as for the trunk rotation.

For every trunk acquisition, we thus obtain sets of *n* values for the two indices. Figure 2 shows the graphical user interface (GUI) used for asymmetry analysis.

In order to make comparisons between the different postures for a given patient, we extracted single values for the two indices from each trunk shape, as follows. The thoracic region was considered to run from section 50 to section 90, section 1 being at the pelvic level. Within that region, the global extremum (either positive or negative) of the index was identified for the preoperative (Pre) standing trunk, along with its section number. For the other postures (left bending (BL), right bending (BR) and postoperative standing (Post)), the local maximum or minimum was identified in the vicinity (+/- 15 sections) of the corresponding section in preoperative standing.

To test the relationship between the change in trunk shape resulting from lateral bending with that resulting from surgical correction, we calculated the differences (Δ_{BSR}, Δ_{TR}) between the Pre measures and those for BL, BR and Post. We also combined the two bendings (Comb(BL,BR)) by taking, for each patient, the Δ_{BSR} or Δ_{TR} value corresponding to the smaller BSR or TR in absolute value. We then evaluated the correlations between the Δs for Post (denoted Δ(Post)) and those for BL, BR and Comb(BL,BR), using Pearson's linear correlation coefficient.

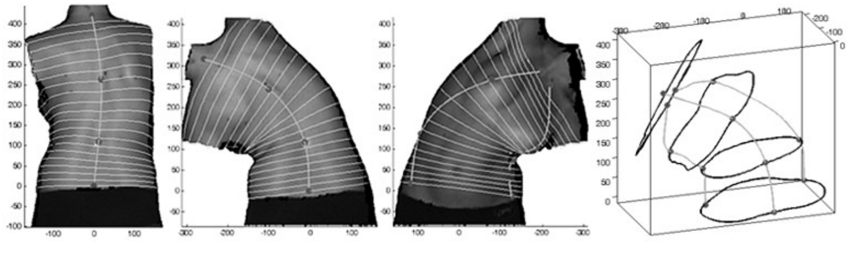

Figure 1. Process for extracting cross sections from the trunk.

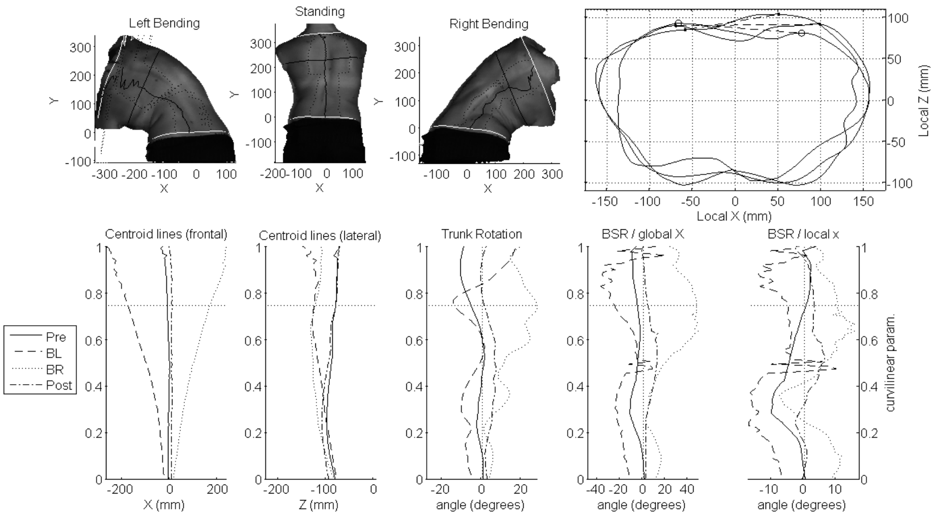

Figure 2. GUI for trunk asymmetry analysis. *Top row:* pre-op. trunk shapes (standing, left and right bending) and cross-sections in local coordinates at given level (with back dual-tangent lines). *Bottom row:* centroid lines of the *n* sections and curves for TR and BSR (global and local) for pre-op. and post-op. postures.

2. Results and Discussion

Table 1 gives the statistical results for the indices differences Δ_{BSR} and Δ_{TR} (mean, standard deviation, range) and the rightmost column shows the correlations coefficients (with p-values). The study in [10] reported that the smallest statistically significant difference (SDD) was 2.5 deg. for the BSR and 1.5 deg. for the axial trunk rotation. Comparing those SDDs with the values in Table 1, the Δ_{BSR} was significant in both BL and BR, while the Δ_{TR} was significant in BR. But in terms of absolute values and looking at individual measures over both bendings, $|\Delta_{BSR}|$ was at or above the SDD threshold in 88% of cases and $|\Delta_{TR}|$ was at or above the SDD in 88% of cases also.

For the statistical correlations, the only poor correlation was for Δ_{TR}(BR) versus Δ_{TR}(Post). The correlations for Δ_{BSR}(BL) and Δ_{BSR}(BL) vs. Δ_{BSR}(Post) were medium, as was Δ_{TR}(BL) vs. Δ_{TR}(Post) ($0.51 < r < 0.62$). Of particular interest are the results when combining the two lateral bendings. For the BSR index, Comb(BL,BR) did not yield an improvement over BL or BR taken separately. However, for the TR, Comb(BL,BR) improved the separate results significantly ($r = 0.766$ with p-value < 0.01).

The logic behind this combination is that, given the complex nature of the external trunk deformity, we don't know beforehand which of the two side bendings will best reflect the effect of surgical correction. Thus, trunk asymmetry reducibility may be assessed by taking the best result (in terms of reducing a given measure) from both bendings. The fact that the statistical relationship is stronger for TR than for BSR may be explained by observing that the TR is inherently more stable than the BSR, as the former is based on the whole shape of each cross-section but the latter only utilizes the posterior portion and is sensitive to errors in detection of the dual tangent line.

Given the restricted patient sample size, we cannot draw any firm conclusions about the relationship between trunk shape changes in lateral bending and post-surgery. However, we may consider these results as providing preliminary favourable evidence that the bending test can effectively be used to assess trunk asymmetry reducibility.

Table 1. Statistical results for Δ_{BSR}, Δ_{TR} and Pearson correlations (with p-values).

N = 13 patients		Mean	Standard dev.	Range	Correl. with Δ(Post)
Δ_{BSR} (degrees)	BL	-8.8	8.6	-18.8 - 9.7	0.559 (0.04709)
	BR	6.9	7.0	0.2 – 21.9	0.621 (0.03104)
	Comb(BL,BR)	-6.3	8.8	-18.3 – 9.7	0.516 (0.07122)
	Post	1.1	5.8	-11.3 - 11.2	N/A
Δ_{TR} (degrees)	BL	0.2	5.8	-12.9 - 9.1	0.513 (0.07297)
	BR	6.7	15.4	-19.1 – 30.1	0.054 (0.86877)
	Comb(BL,BR)	1.7	9.3	-12.9 – 25.4	0.766 (0.00226)
	Post	-2.2	8.0	-14.4 - 10.4	N/A

Conclusion

In this paper, we have proposed an original method to analyse and compare the asymmetry of the scoliotic trunk in the neutral standing and lateral bending positions. We have also presented preliminary results showing that changes in trunk shape can be measured in side bending using our system, and providing evidence that a relationship exists between those changes and the surgical correction of trunk shape. Further, this study shows the usefulness of exploiting both the left and right side-bendings and of capturing the whole trunk and not just the back surface.

Further investigation will be required to better understand the effect of the side-bending test on trunk shape and its relationship with surgical correction. Future work will focus on carrying out a prospective clinical study on a larger cohort of AIS patients.

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