Non-invasive quantitative assessment of scoliosis spinal surgery outcome

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ABSTRACT

Improving the appearance of the trunk is an important goal of scoliosis surgical treatment, mainly in patients' eyes. Unfortunately, existing methods for assessing postoperative trunk appearance are rather subjective as they rely on a qualitative evaluation of the trunk shape. In this paper, an objective method is proposed to quantify the changes in trunk shape after surgery. Using a non-invasive optical system, the whole trunk surface is acquired and reconstructed in 3D. Trunk shape is described by two functional measurements spanning the trunk length: the lateral deviation and the axial rotation. To measure the pre and postoperative differences, a correction rate is computed for both measurements. On a cohort of 36 scoliosis patients with the same spinal curve type who underwent the same surgical approach, surgery achieved a very good correction of the lateral trunk deviation (median correction of 76%) and a poor to moderate correction of the back axial rotation (median correction of 19%). These results demonstrate that after surgery, patients are still confronted with residual trunk deformity, mainly a persisting hump on the back. That can be explained by the fact that current scoliosis assessment and treatment planning are based solely on radiographic measures of the spinal deformity and do not take trunk deformity into consideration. It is believed that with our novel quantitative trunk shape descriptor, clinicians and surgeons can now objectively assess trunk deformity and postoperative shape and propose new treatment strategies that could better address patients' concern about their appearance.

Keywords: scoliosis, surgery, trunk surface topography, shape analysis.

1. INTRODUCTION

Scoliosis is a complex three-dimensional deformity of the spine and the ribcage that leads to visible deformations at the trunk surface[1]. The lateral shift of the trunk, as well as the hump on the back, represent the first signs of scoliosis. These external manifestations constitute patients' major concern and the reason for which they seek treatment[2].

Current scoliosis clinical assessment is mainly based on frontal and lateral radiographs of the entire spine. These images allow clinicians to identify the type of the spinal curvature and its severity by means of the Cobb angle[3], according to which the treatment strategy is decided. For severe scoliosis (Cobb angle above 40°), a surgical treatment is usually considered and classifications based on the spinal curve type[4, 5] help in determining the appropriate surgical approach. The correction of the spine and achieving frontal and sagittal trunk balance are surgeons' top priorities. While improving the appearance of the trunk is an important goal of scoliosis surgical treatment in patients' eyes.

Some clinical tools can be used non-invasively to document trunk asymmetries and the rib hump. The plumb line test[1] consists in dropping a plumb line from C7 vertebral prominence and measuring its deviation from the intergluteal cleft. The scoliometer[6] is an inclinometer that is placed on the back of the patient that is bending forward, perpendicularly to the spine and at the apex of the curvature. It measures the angle of rotation of the back and quantifies the rib hump. Because of their portability and their non-invasiveness, these tools are most frequently used in a scoliosis screening context. However, several studies[7-9] have pointed out a limited reliability associated to the plumb line test and the scoliometer. The absence of reliable tools to assess external trunk deformities has led the clinicians in taking these deformations less into consideration in scoliosis management and treatment planning, while they are at the heart of patients' concern. This often leaves patients confronted with residual trunk deformities.

The difference in trunk's appearance before and after surgery is an important factor upon which depends patients' satisfaction to treatment[10]. An objective and quantitative method to measure trunk deformities could be valuable for treatment planning and for assessing treatment benefits.

Medical Imaging 2013: Biomedical Applications in Molecular, Structural, and Functional Imaging, edited by John B. Weaver, Robert C. Molthen, Proc. of SPIE Vol. 8672, 86721N

Recently, Seoud et al.[11] proposed a new approach to quantify scoliosis trunk deformities from non-invasive trunk surface acquisitions. The trunk shape is represented as a set of three functional measurements corresponding to the rotation of the trunk in the axial plane and its deviations in the coronal and sagittal planes. The functional representation using B-splines allows taking into consideration the deformities not only at the apex, but all along the trunk height. The measurements have proven to be reliable to changes in posture between same day acquisitions.

The objective of this study is to use this novel quantitative descriptor of trunk deformities to compare retrospectively the changes between preoperative and postoperative trunk acquisitions. This investigative study will help documenting quantitatively the outcome of scoliosis spinal surgery in terms of trunk appearance.

2. METHODOLOGY

2.1 Trunk surface acquisition

At Sainte-Justine Hospital Research Center (SJHRC), in Montréal, the trunk surface is acquired and reconstructed in 3D using a non-invasive optical system made of four digitizers (Inspeck/Creaform®, Lévis, QC). Each digitizer acquires and reconstructs in 3D one side of the trunk. Using a calibration procedure, the 4 reconstructed portions are then registered and merged to provide a surface of the complete trunk. The texture of the surface is also mapped onto the mesh.

During the acquisition, the patient stands in upright position with the arms slightly abducted by the sides. The overall process lasts between 4 to 5 seconds[12]. The resulting mesh is dense; it is composed of approximately 60.000 nodes. It is also highly accurate[13] with a precision of about 1.1±0.9 mm overall the trunk surface.

Prior to the acquisition, markers are placed on the surface over 4 anatomical landmarks: the vertebral prominence (VP), the left and right anterior superior iliac spines and the midpoint of the posterior superior iliac spines (MPSIS). These markers can be identified on the textured mesh. In order to compare trunk surfaces acquired at different moments in time, each trunk reconstruction is transposed into a patient-specific reference frame, based on the 3D coordinates of 3 anatomical landmarks: the left and right anterior superior iliac spines and the (MPSIS).

2.2 Trunk shape measurements

To quantify visible trunk deformities, we used the methodology presented in our previous paper[11]. Briefly, 300 horizontal trunk cross-sections are automatically extracted along the trunk height (Figure 1, on the left), starting from MPSIS and going up to the VP. The cross-sections are equally spaced along the vertical axis.

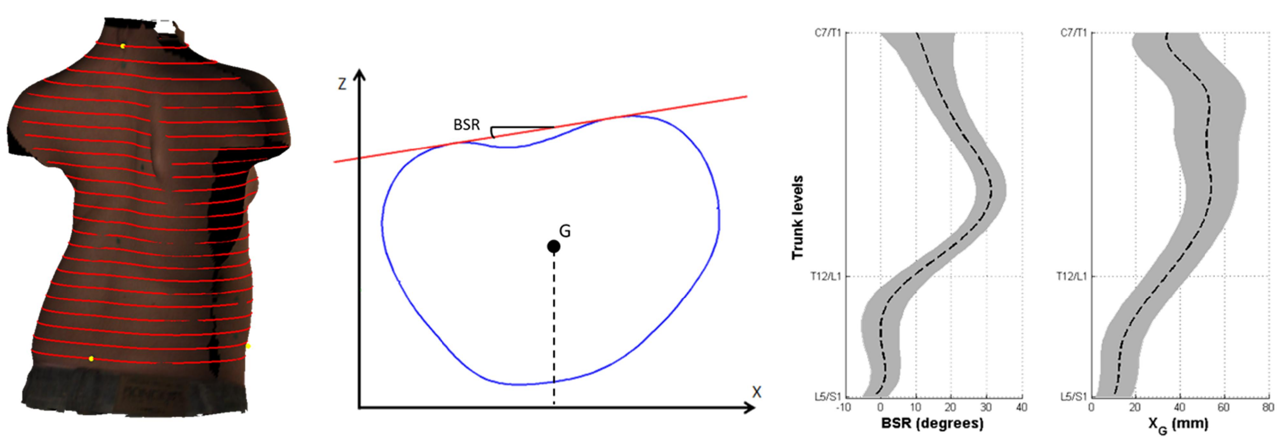

Figure 1- Computational step for trunk shape measurements, starting with cross-sections extraction (on the left), then cross-sectional measurements computation (in the middle) and functional representation of BSR and XG as functions of trunk levels (on the right).

For each cross-section, two measurements are computed (Figure 1, in the middle). The first one quantifies the lateral deviation of the section in the coronal plane; it corresponds to the X-coordinate of the section's center point (noted XG). The second measurement quantifies the section's axial rotation; it is computed in the axial plane as the angle between the dual tangent to the back portion of the section and the coronal plane (noted BSR for back surface rotation).

The multilevel raw measurements are then converted to a functional form[14] using a set of 10 cubic B-spline basis functions (Figure 1, on the right). This allows for dimensionality reduction as well as measurements smoothing. BSR and XG indices are thus represented as continuous and smooth functions of trunk height (noted *t*): $f^{BSR}(t)$ and $f^{XG}(t)$.

2.3 Assessment of the surgical outcome

In order to evaluate the changes in trunk shape after scoliosis surgery, we computed the relative correction rate (CR), independently for both measurements:

$$CR^{BSR}(\%) = 100 \times \frac{\int \left| f_{preop}^{BSR}(t) \right| dt - \int \left| f_{postop}^{BSR}(t) \right| dt}{\int \left| f_{preop}^{BSR}(t) \right| dt}$$

$$CR^{XG}(\%) = 100 \times \frac{\int \left| f_{preop}^{XG}(t) \right| dt - \int \left| f_{postop}^{XG}(t) \right| dt}{\int \left| f_{preop}^{XG}(t) \right| dt}$$

A positive value of the correction rate indicates an improvement in the appearance of the trunk, while a negative value indicates a worsening in trunk deformity.

3. VALIDATION METHOD

For this study, we used retrospective data of adolescent patients with scoliosis who were surgically treated at Sainte Justine's Hospital in Montreal. We only considered data of patients with the same type (Lenke1A) of scoliosis spinal curvature according to Lenke's radiographic classification[4]. Moreover, we only included data of patients who had a trunk surface acquisition at most two months before surgery and an acquisition at least 6 months after surgery.

A total of 36 patients, of which 31 females and 5 males, met our inclusion criteria. Table 1 summarizes the information about the cohort.

Table 1 - Information about the cohort

	Mean	**Standard deviation**	**Range**
Age at surgery (years old)	16	1.8	12 - 18
Height at surgery (cm)	163	8	143 - 178
Weight at surgery (kg)	54	8.5	33 - 67
Preoperative thoracic Cobb angle (°)	60	10	40 – 96

All patients in our cohort had the same posterior surgical approach; except one patient (P19) who had both anterior and posterior approaches. Surgeries were conducted by three different orthopedic surgeons.

4. RESULTS

Figure 2 illustrates the correction rates for BSR and XG among the cohort. It clearly shows that, in most cases, surgery achieves a very good correction of the lateral deviation of the trunk (median value of 76%) and a moderate correction of the back surface axial rotation (median value of 19%). Table 2 summarizes the descriptive statistics.

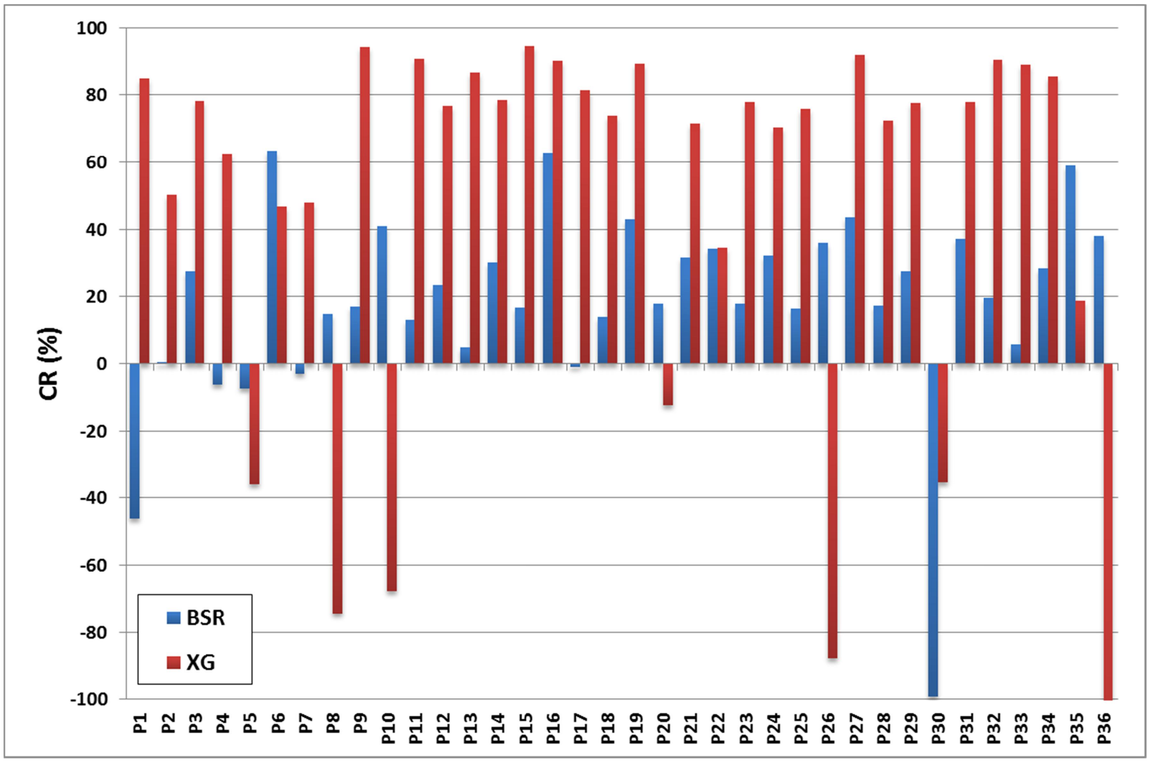

Figure 2 - Correction rates (CR) for back surface rotation (BSR) and lateral shift (XG) for all the 36 patients.

Table 2- Descriptive statistics of the correction rates (CR^{BSR} and CR^{XG}).

N=36	CR^{BSR} (%)	CR^{XG} (%)
Mean	19	49
Standard deviation	29	58
Median	19	76

Figure 3 illustrates the cases of two female adolescents with scoliosis (P16 and P17) having similar severity (Cobb angles of 74° and 68° respectively). They both underwent the same surgery. Postoperatively, the reduction of the Cobb angle was the same with 18° Cobb angle after surgery. Even though the correction of the spinal curve was similar in both cases and successful in clinicians eyes, the changes on the trunk surface are rather different. For patient P16 the corrections of the back surface rotation and the coronal trunk deviation are both significant. The maximal BSR decreases from 24° to 11°. While, for patient P17, the correction of the back surface rotation is almost inexistent. The maximal BSR decreases from 16° to 14°, which is insignificant.

Moreover, even though the correction rate of the Cobb angle is above 70% in both cases, a rib hump still remains on the back of both patients after surgery.

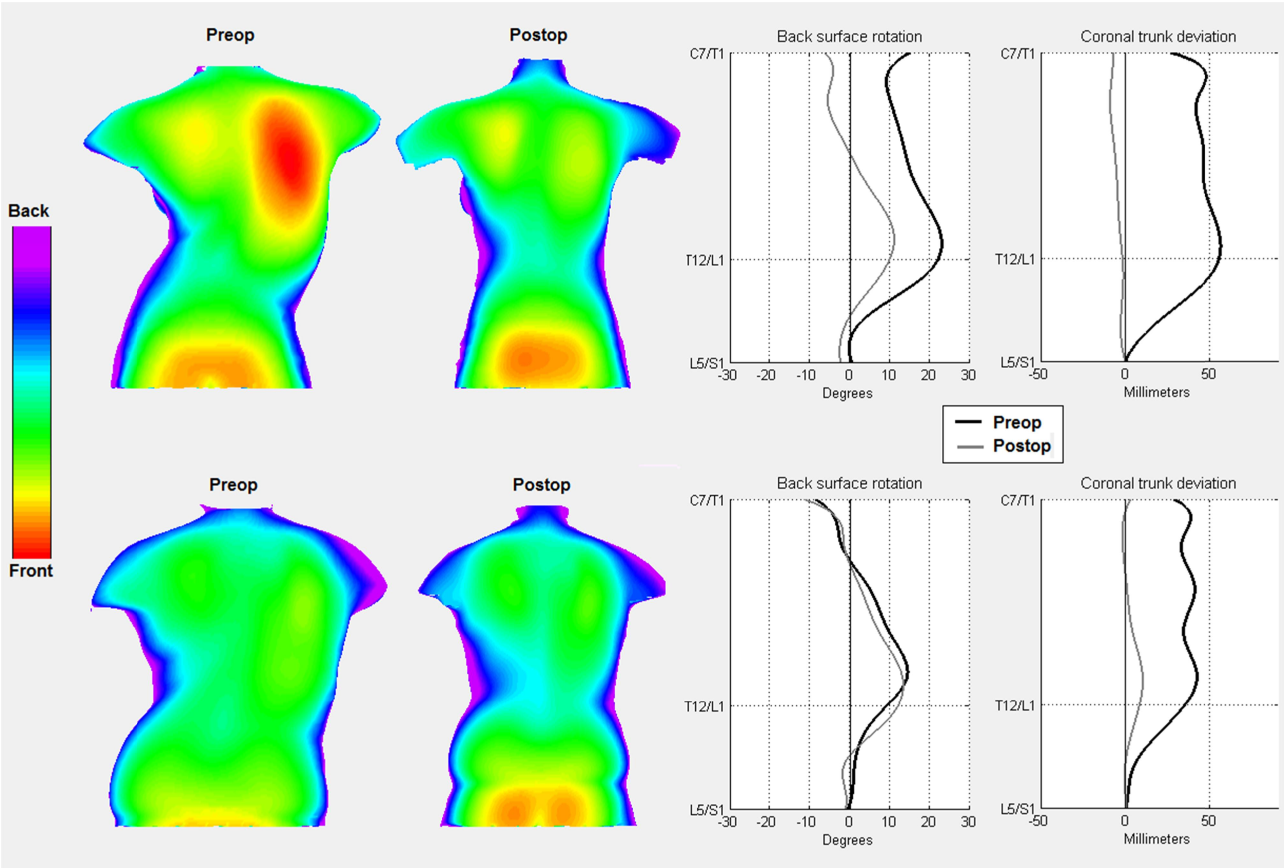

Figure 3 – Clinical examples (P16 on the top row and P17 on the bottom row). The first two columns show the depth map of the back of both patients before and after surgery. The color map is the same in the 4 images. The graphs on the right side illustrate the functional measurements (BSR and XG) as functions of trunk height, before and after surgery for both patients.

5. DISCUSSION

The results of this investigative study demonstrate how a similar correction of the spinal deformity can lead to different results on the trunk shape. In fact, the choice of the surgical strategy is based solely on the radiographic evaluation of the spine. Trunk deformities are not taken into consideration for treatment planning. It is believed that the lack of objective and reliable measurements for assessing and quantifying trunk deformities has put the external manifestations of scoliosis on a second level in clinical evaluation and treatment while it is at the heart of patients' concerns.

In our previous publication[11], we proposed a novel descriptor for scoliosis trunk deformity and we demonstrated its reliability with respect to changes in patient's positioning between two consecutive acquisitions. In the present study, this new descriptor is used for the first time to evaluate objectively and quantitatively the surgical outcome in terms of trunk appearance.

Several studies have tried to assess the cosmetic outcome of scoliosis spinal surgery using either self-assessment questionnaires administered to patients and their parents[15], or qualitative surveys for surgeons to complete using photographs of the patients before and after surgery[16]. However, these assessments are highly subjective.

Quantitative approaches have been proposed in the literature[17, 18]. They rely on trunk surface measurements taken at the most deformed level along the trunk height. Nevertheless, comparing only maximum values overlooks the extent of the deformity. The rib hump severity for example might be improved, suggesting a correction of the deformity; however it could be flattened along the trunk height resulting in a more extensive deformity. By considering the whole measurement profile, our functional measurements together with our correction rate's definition overcome this limitation.

6. CONCLUSION

The results of this investigation demonstrate clearly that after surgery, patients are still confronted with residual trunk deformity, mainly a persisting hump on the back. That can be explained by the fact that current scoliosis assessment and treatment planning are based solely on radiographic measures of the spinal deformity. It is believed that with our novel quantitative trunk shape descriptor, clinicians and surgeons can now objectively assess trunk deformity and treatment outcome and think of possible new treatment strategies that could better address patients' concern about their appearance.

ACKOWLEDGEMENTS

The authors would like to thanks Philippe Debanné and Manivone Savann for their valuable technical help.

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