3.4 Assessment of trunk post-operative asymmetry correction

A secondary aim of the study presented in [13] was to evaluate the feasibility of applying the external surface measurements to quantifying the effect of spinal instrumentation on cosmetic appearance. To do so, two exemplar AIS cases having undergone surgery were selected; for both patients, the Cobb angle was 74° prior to surgery and 16° afterwards. Figure 7 shows photos of their backs before and after the surgery. External surface measurements were computed and compared; transverse decomposition of the trunk used 250 horizontal cross-sections.

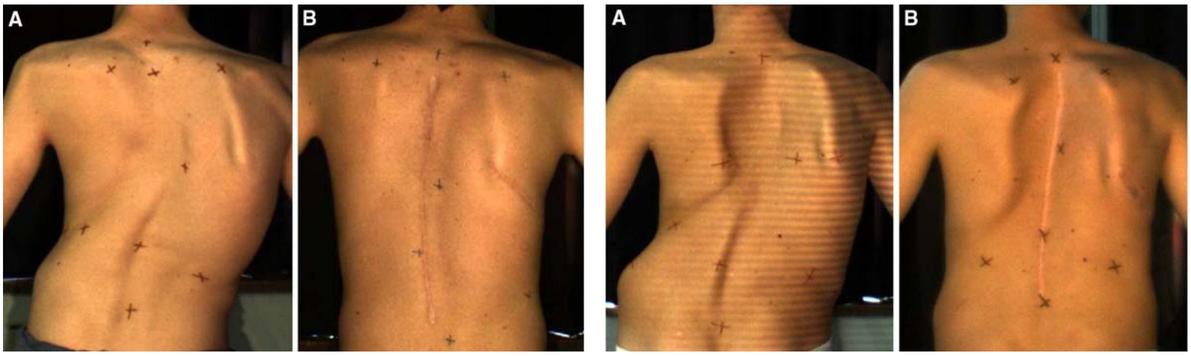

Fig. 7.Two cases of AIS before (A) and after (B) spinal surgery: patient 1 (left) and patient 2 (right).

Statistically, the preoperative external asymmetries were significantly different for most of the measurements. Whereas both cases showed good correction in the frontal plane, the ranges of corrections in other planes were not comparable. The change in the shape of the cross-sectional sections was particularly representative of the overall correction. Indeed, patient 2 showed better correction of the max. BSR and max. TR values (respectively 8.1° and 6.2° of correction) than patient 1 (respectively 1.8° and 2.6° of correction). This particular result is in keeping with a visual observation of the two patients' cosmetic improvements, which can be done by examining Figure 7.

4. Simulation of trunk post-operative shape correction

Spinal surgery for scoliosis consists in rectifying the spine shape using metal rods anchored to the vertebrae by means of screws and hooks. The prediction of surgical outcome is a fundamental element of any preoperative evaluation. Currently, the clinical method to define a surgical strategy and estimate the result of curve correction relies primarily on radiographic analysis of spinal flexibility and on the surgeon's own experience. To further assist the clinician during surgical planning, a biomechanical simulator is currently being developed at CHU Sainte-Justine to identify the optimal configuration of the implants to best correct the spinal deformities [15]. However, neither this simulator nor the spinal flexibility analysis consider the soft tissues of the trunk in order to provide information on the patient's external appearance after the intervention. For the surgeon, the residual trunk asymmetry proves highly subjective and his experience remains his only asset. This is problematic considering that the main reason to prescribe an operation comes initially from the patient's dissatisfaction with their apparent deformity. At present, there is no tool available to estimate the effect of treatment on the patient's external appearance, even though surgeons' assessments of treatment outcomes are not significantly correlated with patient satisfaction [16].

Therefore, the goal of a recent project was to develop a simplified physical model of the deformable tissues between the skin surface (epidermis) and bone structures of the trunk in order to visualize in 3D and assess the effect of scoliosis surgery on the patient's external appearance [17]. This research focused only on the soft tissues since biomechanical modeling of the bone structures is the subject of another ongoing project. Consequently, an expected postoperative configuration of the bone structures served as our basis to predict the external appearance after scoliosis surgery.

To achieve our goal, we first proposed a methodology to build a simplified system to model the different deformable structures of the trunk. Initially, 3D pre and postoperative reconstructions of the bone structures were obtained from standard radiographs while non-invasive 3D optical digitizers acquire the external surface of the trunk using white non-ionizing structure light. Following certain mesh pre-processing, we developed a generic method to generate three different tetrahedral layers starting from the external surface of the trunk to represent the skin, fat and muscles. From these new layers, a generalized particle system based on elastic potential energy was defined. Forces preserving distance, area and volume constraints were calculated to describe the physical behavior of the various soft tissues. Finally, a rigid articulated model of the bone structures was created in order to transform

the internal preoperative configuration to the postoperative state. By solving a set of dynamic equations, the displacements of this rigid model deform the simplified soft tissue layers of the trunk in order to predict the external appearance after scoliosis surgery.
We validated this system by comparing the simulated and actual postoperative trunk surface shapes of an AIS patient having undergone surgery. For this purpose, clinical indices of torso asymmetry were computed and compared by using cross-sections of the simulated and acquired postoperative external geometries at various vertebral levels. A preliminary evaluation study for this patient showed a mean absolute error of 1.38° in the thoracic region and 3.26° in the lumbar region on the BSR index while the mean absolute error on the rib hump index (difference between left and right posterior rib humps, as a distance) was evaluated at 2.73 mm (thoracic) and 3.83 mm (lumbar). Figure 9 shows the simulated and actual post-op trunk shapes for the exemplar patient.
This project, has allowed us to demonstrate the feasibility of simulating the external trunk appearance resulting from corrective scoliosis surgery. A software prototype allowing a user to interactively simulate the effect of scoliosis surgery on the external trunk appearance was also developed in this project (see Figure 9). However, our results reveal the limits of the simplified modeling framework. Improved accuracy of simulation results would require the development of a more refined meshing of the different structures of the human trunk including calibrated physical properties.

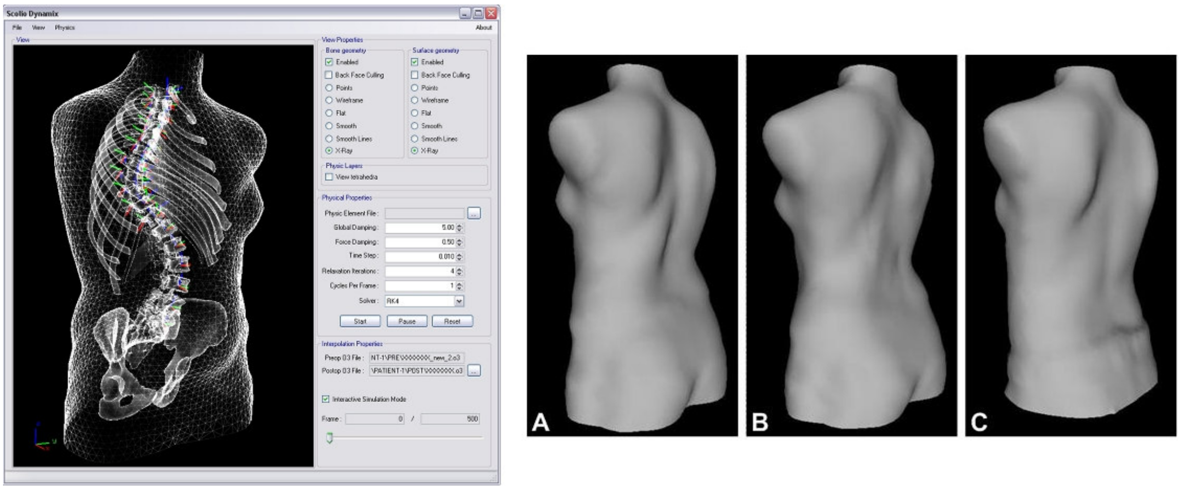

Fig. 9. Left: Software GUI for controlling physical model simulation. Right: Sample result of a simulation on the external trunk shape: A) real pre-op trunk shape; B) simulated post-op trunk shape; C) real post-op trunk shape.

5. Summary

In summary, we have presented in this article some of our research projects at CHU Sainte-Justine and École Polytechnique de Montréal making use of non-invasively acquired surface topography of the human trunk to study trunk asymmetry and the effects of corrective surgery in adolescent idiopathic scoliosis, and to simulate the effect of surgery on trunk external shape.

5.1. Future work

Several avenues for future work present themselves to improve and further validate the methodologies and results presented in this paper. Firstly, we aim to carry out the evaluation of trunk post-operative asymmetry correction on a prospective cohort of AIS patients. This larger study will allow us to better understand the effect of the surgery on trunk shape as expressed by different asymmetry indices, as well as the external correction’s relationship with the correction of underlying bone structures, i.e. the spine and ribcage.
For the simulation of trunk post-operative shape correction, the numerical model must be validated on a group of patients for whom pre- and post-surgery surface acquisitions are available. Furthermore, we will focus on constructing a personalized multi-layer geometric model of the trunk from multimodal image fusion integrating surface topography, 3D radiographic reconstruction and MRI scans. We will also explore how to best exploit *a priori* data to calibrate the properties of the physical model.

5.2. Potential benefits for the healthcare system

The proposed approach for trunk shape analysis is complementary to the standard radiographic analysis used in surgery planning and evaluation of surgical outcome. Our methodology distinguishes

itself by evaluating what is perceived by the patient as the major problem (asymmetrical appearance and rib hump) and what is considered by patients as the most important outcome, as opposed to what surgeons currently evaluate as the main outcome with Cobb angles and sagittal and coronal balance of the spine. By the same token, it could form the basis for recommendations on surgical strategies most likely to improve the patient's external appearance.
As for the surgical simulator based on a deformable model of the trunk, the potential benefits of this system will be as follows: 1) it will assist the surgeon, together with the patient, in deciding on the best surgical approach based on the resulting external trunk appearance; 2) it will provide an enhanced preoperative planning tool allowing the surgeon to take into account such factors as the residual external trunk asymmetry after the operation, when deciding on a surgical strategy including the indication for rib resection or anterior spine release; 3) it will allow the patient to readily understand the probable outcome as well as the risks of surgery and to be involved in the decisional process; 4) it has potential for generalized use by orthopedic surgeons.

References

1. Reamy, B. V., Slakey, J. B., (2001): "Adolescent idiopathic scoliosis: review and current concepts", American Family Physician, Vol. 64, No.1, pp. 111-116.
2. Labelle, H., Dansereau, J., Bellefleur, C., Jéquier, J. C., (1995): "Variability of geometric measurements from three-dimensional reconstructions of scoliotic spines and rib cages", European Spine Journal, Vol. 4, No. 2, pp. 88-94.
3. Goldberg, C. J., Kaliszer, M., Moore, D. P., Fogarty, E. E., Dowling, F. E., (2001): "Surface topography, Cobb angles and cosmetic change in scoliosis", Spine, Vol. 26, pp. E55–E63.
4. Pratt, R. K., Burwell, R. G., Cole, A. A., (2002): "Patient and parental perception of adolescent idiopathic scoliosis before and after surgery in comparison with surface and radiographic measurements", Spine, Vol. 27, pp. 1543–1552.
5. Haher, T. R., Merola, A., Zipnick, R. I., et al., (1995): "Meta-analysis of surgical outcome in adolescent idiopathic scoliosis. A 35-year English literature review of 11,000 patients", Spine, Vol. 20, No. 14, pp. 1575-1584.
6. Moreland, M. S., Pope, M. H., Wilder, D. G., (1981): "Moiré fringe photography of the human body", Medical Instrumentation, Vol. 15, pp. 129–132.
7. Stokes, I. A. F., Armstrong, J. G., Moreland, M. S., (1988): "Spinal deformity and back surface asymmetry in idiopathic scoliosis", Journal of Orthopaedic Research, Vol. 6, No. 1, pp. 129-37.
8. Dawson, E. G., Kropf, M. A., Purcell, G., (1993): "Optoelectronic evaluation of trunk deformity in scoliosis", Spine, Vol. 18, pp. 326–331.
9. Theologis, T. N., Fairbank, J. C. T., Turner-Smith, A. R., (1997): "Early detection of progression in adolescent idiopathic scoliosis by measurement of changes in back shape with the integrated shape imaging system scanner", Spine, Vol. 22, pp. 1223–1227.
10. Thometz, J. G., Lamdan, R., Liu, X. C., (2000): "Relationship between Quantec measurement and Cobb angle in patients with idiopathic scoliosis", Journal of pediatric orthopedics, Vol. 20, pp. 512–516.
11. Jaremko, J. L., Poncet, P., Ronsky, J., (2002): "Indices of torso asymmetry related to spinal deformity in scoliosis", Clinical biomechanics, Vol. 17, No. 8, pp. 559-568.
12. Pazos, V., Cheriet, F., Song, L., Labelle, H., Dansereau, J., (2005): "Accuracy assessment of human trunk surface 3D reconstructions from an optical digitizing system", Medical & biological engineering & computing, Vol. 43, No. 1, pp. 11-15.
13. Pazos, V., Cheriet, F., Dansereau, J., Ronsky, J., Zernicke, R. F., Labelle H., (2007): "Reliability of trunk shape measurements based on 3-D surface reconstructions". European Spine Journal, Vol. 16, pp. 1882-1891.
14. Song, L., Lemelin, G., Beauchamp, D., Delisle, S., Jacques, D., Hall, E. G., (2001): "3D measuring and modeling using digitized data acquired with color optical 3D digitizers and related applications", Proceedings of 12th Symposium on 3D technology, Yokohama, Japan, pp 59–77.
15. Aubin, C.-E., Labelle, H., Ciolofan, O., (2007): "Variability of spinal instrumentation configurations in adolescent idiopathic scoliosis", European Spine Journal, Vol. 16, No. 1, pp. 57-64.
16. Buchanan, R., Birch, J. G., Morton, A. A., Browne R. H., (2003): "Do you see what I see? Looking at scoliosis surgical outcomes through orthopedists' eyes", Spine, Vol. 28, No. 24, pp. 2700-2705.
17. Dionne, O., Assi, C. K., Guibault, F., Labelle, H., Cheriet, F., (2010): "Postoperative Appearance Simulation of the External Outcome of Spine Surgery: Preliminary Results", Research into Spinal Deformities 7, C.-E. Aubin, I.A.F. Stokes, H. Labelle and A. Moreau (eds), p. 270.