Assessment of Brace Local Action on Vertebrae Relative Poses

Jonathan Boisvert[a,b,c], Farida Cheriet[a,c], Xavier Pennec[b], Nicholas Ayache[b] and Hubert Labelle[a]
[a] *St-Justine Hospital, 3175 Côte-Ste-Catherine, Montréal, Canada*
[b] *INRIA Sophia-Antipolis, 2004 Des Lucioles, Sophia-Antipolis, France*
[c] *École Polytechnique de Montréal, C.P. 6079, succ. Centre-Ville, Montréal, Canada*

Abstract. Bracing is a widely used treatment of scoliosis, but there is still no consensus about its actual effect. Previous studies were based on global descriptors of the spine shape (Cobb angle, plane of maximal deformity, *etc.*). We present a new method to analyze braces effects at a finer scale and to find which vertebral levels are significantly affected by this treatment. The proposed method compares a group of patients treated with a brace and a control group. The 3D spine geometry of the patients from the two groups was digitized on two separate occasions: with and without brace (first group) or two times without brace (control group). The modifications of the vertebrae relative poses (combination of relative translation and rotation between consecutive vertebrae) were then extracted from 3D reconstructions. Centrality and dispersion measures of the relative poses modifications were computed using a method that take into account the non-linearity of the rotation matrix. Then, finally, multivariate hypothesis tests were used to compare the centrality and dispersion of the two groups. The method was applied to 28 untreated scoliotic patients and 41 patients treated with a Boston brace. Significant differences ($p<0.01$) between the centrality and dispersion measures of the relative poses modifications were respectively found from T1 to T6 and from T8 to L1. Those significant differences concords with the back flattening effect and the spatially limited correction found in other studies; however the proposed method offers a more specific evaluation of the localization of those effects.

1. Introduction

Bracing had become a well accepted treatments for mild cases of adolescent idiopathic scoliosis (AIS) because it is non-invasive and it does not pose risks to the patient's health. However, the actual effect of such treatment is difficult to measure because the modifications of the spine geometry are small and there is no consensus about the localization of that effect.

The conventional method used to measure the effect of a brace is to compute clinical indices (such as the Cobb angle, the apical rotation, the plane of maximal deformity, etc) and to compare the progression of those indices for a control group and a group of patients treated with a brace [1,2,3].

However, this method of evaluation has many drawbacks. First of all, most of the clinical indices used are solely based on an anterior-posterior radiograph, thus discarding the three dimensional nature of the spine curvature. Second, the information gathered using those clinical indices is dependant of the shape of the whole spine and do not offers well localized information about the action of the treatment. Finally, the interpretation of the results could be difficult because the indices are usually not independent.

Moreover, previous studies were only concerned with the mean deformation caused by the brace and not with its variability. However, a modification of the variability could be an indication that the correction is more or less important for large curves than it is for smaller curves (for example) which would be valuable clinical information.

To circumvent those drawbacks and limitations, we propose to apply an hypothesis testing procedure directly to the spine geometry without computing any intermediate index. The spine geometry will be described using the relative poses (relative positions and orientations) that separates the local coordinates systems of neighbouring vertebrae. A similar approach was proposed by Petit et al. [4] to compare two surgical instrumentations. However, only the mean position of the center of rotation was studied. The proposed method will be applied to the relative poses used to describe the geometry of the spine. Furthermore, the hypothesis tests will not only compare the mean effect on the spine shape, but also the variability of this effect.

2. Method

The proposed method can intuitively be subdivided in three steps. First of all, the modification of the vertebrae's relative poses is computed. This modification takes the form of a vector of rigid transforms (combination of a rotation and a translation). Then, the mean and variability of those rigid transforms is computed. Finally, a hypothesis testing procedure determines if there is significant differences between patients treated with a brace and patients from a control group.

2.1. Vertebrae Relative Poses Computation

The spine geometry was described using the relative poses that separate the local coordinates systems of neighbouring vertebrae. Furthermore, the effect of a brace on the spine geometry is simply modeled by the set of rigid transforms that must be applied to the relative poses computed without the brace to obtain the relative poses computed when the patient is wearing his brace.

In other words, the spine geometry is described by the relative poses T_1, T_2, *etc.* and the effect of the brace is modeled by the rigid transforms ΔT_1, ΔT_2, *etc.* illustrated at Figure 1.

The relative poses computation is achieved by reconstructing a 3D model of the spine from a pair of calibrated radiographs [5] and then rigidly registering each vertebra to its first upper neighbour.

2.2. Mean and Covariance Computation

The rigid transforms used to model the effect of a brace are composed of a rotation and a translation. Computing the mean value of the translation is easy, since translation is described by three real numbers (it belongs to R^3). However, the rotation is more difficult to manipulate, because rotations cannot by added or multiplied by a scalar (they naturally belongs to a Lie group). Thus, just summing a set of rotation matrices and dividing the total by the number of elements might not produce a valid rotation matrix and the result would not be invariant with respect to a change of coordinates system.

Those difficulties can be solved by using the Fréchet mean, which is a generalization of the conventional mean. This generalization is based on the minimization of the distances between the elements of a set. Moreover, its computation is easy if one knows the exponential and log maps associated with the chosen distance function. Furthermore, the variability of the rigid transforms can be captured by computing a covariance matrix in the tangent space of the Fréchet mean (the equations needed to compute the Fréchet mean and the covariance on rigid transforms can be found in [6]).

2.3. Hypothesis Testing

After computing the mean and variability from a group of patient treated using a brace and a control group, the next important step is to determine if they differ significantly. This can be achieved by using multivariate hypothesis testing. Thus, the Hotelling's T^2 test will be used to compare the mean of spine shape deformation and the variabilities will be compared using the Box's M test.

However, these two tests assume a normal distribution of the measures (details about the derivations and the underlying assumptions of those two tests can be found in Rencher et al. [7]). Therefore, we have to assume that both sets of rigid transforms are normally distributed in the tangent spaces of the Fréchet mean of the two sets. This assumption is generally justifiable in the case of braces effects because the deformation of the spine and its variability are small.

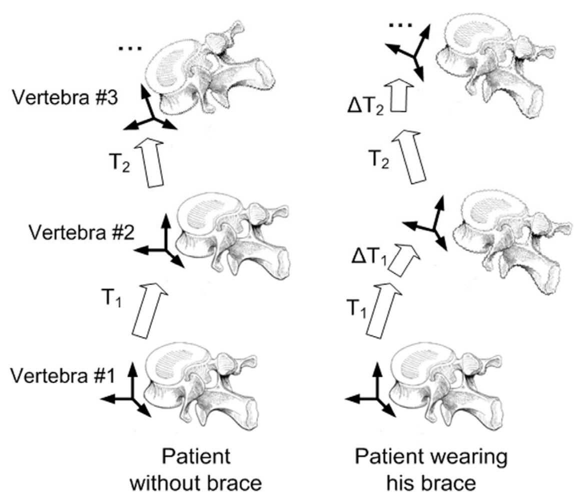

Figure 1. The action of a brace expressed as rigid transforms (ΔT_1, ΔT_2, *etc.*) on the spine geometry expressed using relative poses (T_1, T_2, *etc.*)

2.4. The Case of the Boston Brace

To demonstrate the practical significance of the method described in this article, two groups of patients were selected for comparison. The first group was composed of 39 scoliotic patients that were treated using a Boston brace. All the patients of this group had received two stereo radiographic examinations: one without brace and one while wearing their brace (both examinations were performed on the same day). The second group (which is the control group) was composed of 26 scoliotic patients that did not received any orthopaedic treatment and had received two stereo radiographic examinations (for ethical reasons, the two examinations were conducted six months apart).

The stereo radiographic examinations were used to reconstruct 3D spine models and the method described in the previous subsections was used to compare the mean modification of the spine shape as well was the variability of the spine shape modification for the two selected groups.

3. Results

The mean modifications of the spine shape (see Figure 2) along with the rotational and translational variabilities were computed for the group treated using the Boston brace and the control group. The variability of the Boston brace effect appeared to be more important in the lower part of the thoracic spine (approximately from T7 to L1, with a maximum at T11). Moreover, the mean curve in frontal view as well as the kyphosis and lordisis found in the sagittal view seemed to be reduced by the treatment.

Hypothesis tests were also performed to detect statistically significant differences between the control group and the group treated with the Boston brace. The results of those tests are presented in Table 1. In this table, p-values lower than 0.01 are marked with a star ("*"), p-values lower than 0.001 are marked with a two stars and p-values lower than 0.0001 are marked with a three stars.

4. Discussion and Conclusion

The comparison of the group treated using the Boston brace and the control group outlined two significant differences. First of all, there was a significant difference between the mean deformations of the spine geometry from T1 to T6. This suggest a systematic effect of the Boston brace on the geometry of the thoracic spine of all patients treated with it regardless of strength and shape of the curvature caused by scoliosis. This effect could be associated with what was described in earlier studies as the "flat back" effect of the Boston brace.

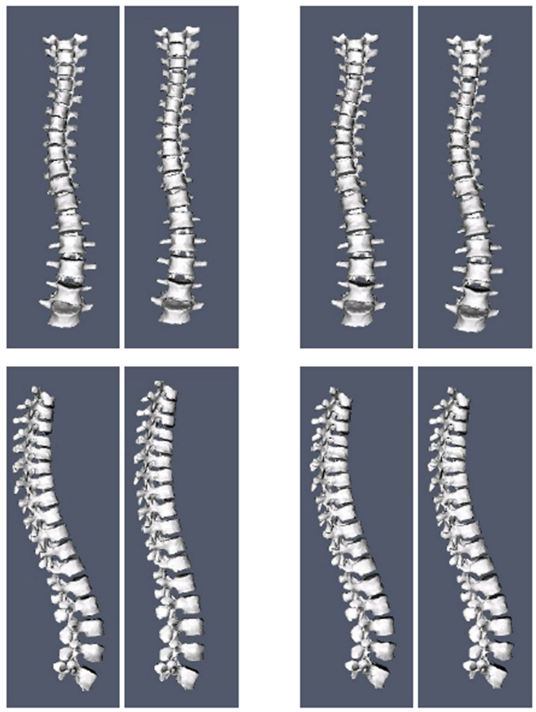

Figure 2. From left to right: mean shape without brace, with the brace, of the control group at the first acquisition and of the control group at the second acquisition Top : Frontal view. Bottom: sagittal view

	Mean		Covariance	
T2 → T1	2.5e-4	**	1.1e-1	
T3 → T2	1.7e-3	*	5.6e-2	
T4 → T3	8.4e-9	***	1.4e-2	
T5 → T4	2.1e-3	*	1.8e-1	
T6 → T5	6.8e-3	*	1.7e-1	
T7 → T6	2.5e-2		1.3e-1	
T8 → T7	5.9e-2		4.3e-2	
T9 → T8	5.2e-1		7.5e-6	***
T10 → T9	2.3e-1		5.2e-4	**
T11 → T10	3.6e-1		2.3e-5	***
T12 → T11	8.2e-1		4.4e-6	***
L1 → T12	6.7e-1		5.3e-4	**
L2 → L1	9.3e-1		2.9e-1	
L3 → L2	3.4e-2		2.9e-1	
L4 → L3	3.0e-2		7.3e-2	
L5 → L4	3.1e-1		1.3e-2	

Table 1. Statistical significance of the difference between the means and the covariance matrices of a control group and a group of patients wearing a Boston brace.

The second significant difference between the two groups of patients was observed between the variabilities from T8 to L1. A significant difference between variabilities is an indication that the Boston brace brings scoliotic spines closer to a `` healthy '' spine shape (which is the goal of the treatment). More serious scoliotic cases were submitted to larger corrections than mild cases which lead to larger variabilities. Therefore, this difference suggests that most of the therapeutic effect of the Boston brace is localized in the region from T8 to L1.

One of the limitations of the proposed method is that the assumption of normality needed to apply the T^2 and M test is quite restrictive. For example, for larger deformations the non-linearities related to the rotation could lead to asymmetric distributions (for which the normality assumption would be hard to justify).

Finally, a method to assess the local effects of a brace was presented. The proposed method was applied directly to a representation of the spine geometry (the vertebrae's relative positions and orientations) which lead to results that are more precisely localized than those found in previous studies. The proposed method was used to compare a control group with a group of patients treated with a Boston brace and significant differences were found between the mean modifications of the geometry in the upper thoracic spine and between the geometry modification variabilities in the lower part of the thoracic spine. Those results concord with previous results about the “flat back” effect and the idea that the Boston brace might not have a therapeutic effect on the whole spine but on a relatively small part of the spine. Furthermore, the proposed method could also be used in various contexts such as motion or posture analysis or studies about the effect of corrective surgeries.

Acknowledgement

This work was funded by the Natural Sciences and Engineering Research Council (NSERC) of Canada, the Quebec's Technology and Nature Research Funds (Fonds de Recherche sur la Nature et les Technologies de Québec) and the Canadian Institutes of Health Research (CIHR).

References

[1] T. B. Grivas, E. Vasiliadis, T. Chatziargiropoulos, V. D. Polyzois, and K. Gatos. The effect of a modified boston brace with anti-rotatory blades on the progression of curves in idiopathic scoliosis: aetiologic implications. Pediatr Rehabil, 6:237–242.

[2] V. Vijvermans, G. Fabry, and J. Nijs. Factors determining the final outcome of treatment of idiopathic scoliosis with the boston brace: a longitudinal study. J. Pediatr. Orthop. B, 13:143–149, May 2004.

[3] H. Labelle, J. Dansereau, C. Bellefleur, and B. Poitras. Three-dimensional effect of the boston brace on the thoracic spine and rib cage. Spine, 21:59–59, Jan 1996.

[4] Yvan Petit, Carl-Eric Aubin, and Hubert Labelle. Spinal shape changes resulting from scoliotic spine surgical instrumentation expressed as intervertebral rotations and centers of rotation. J. Biomech, 37:173–180, 2004.

[5] C.-E. Aubin, J. Dansereau, F. Parent, H. Labelle, and J.A. de Guise. Morphometric evaluations of personalised 3d reconstructions and geometric models of the human spine. Med. Bio. Eng. Comp., 35, 1997.

[6] J. Boisvert, X. Pennec, N. Ayache, H. Labelle, and F. Cheriet. 3D anatomical variability assessment of the scoliotic spine using statistics on lie groups. In Proceedings of ISBI, 2006.

[7] A. C. Rencher. Methods of Multivariate Analysis. Wiley, 2002.