Biomechanical loading of the sacrum in pre- and post operative adolescents idiopathic scoliosis

1,2 Saba Pasha, 1,2,3 Carl-Eric Aubin, 2,3 Stefan Parent, 2,3 Hubert Labelle, 2,3 Jean-Marc Mac-Thiong

1 Department of Mechanical Engineering, Ecole polytechnique de Montreal, Montreal, QC, CANADA
2 Research Center, Sainte-Justine University Hospital Center, QC, CANADA
3 Department of Surgery, Université de Montréal, QC, CANADA
email: saba.pasha@polymtl.ca

INTRODUCTION

Posterior spinal instrumentation and fusion techniques are used over decades to correct spinal deformities higher than 40 degrees in scoliotic subjects [1]. Although these methods are successfully decreased the spinal curvature in scoliosis, the biomechanical loading of the distal unfused vertebrae is not well studied after operation. Among unfused vertebrae sacrum, the connective vertebra between the spine and pelvis, is of special interest; the biomechanical loading of the sacrum contributes to the transferred load between the spine and lower extremities and hence impacts the postural equilibrium of the subject [2]. This study tries to present the biomechanical loading of the sacrum in scoliotic patients with different curve types before and after spinal fusion via a comprehensive finite element model (FEM).

METHODS

5 right thoracic and 5 left thoracolumbar/lumbar AIS female subjects who had undergone a posterior spinal instrumentation and fusion with an average of 16 months [12-18] follow-up were selected from the database in our institution. Exclusion criteria of receiving a previous spinal fusion surgery and a spinal deformity (Cobb angle) less than 20 degrees were applied. The medical dossier and pre- and post-operative bi-planar radiographs of the patients were consulted. A gender- age match group of 12 asymptomatic controls with no history of spinal disease were added to the protocol.

3-dimensional reconstruction of the spine, pelvis, ribcage, and the position of the femoral heads were created from digitized landmarks on the postero-anterior and lateral x-rays by a freeform deformation technique along with a detailed atlas of the spine, ribcage, and pelvis [3]. Biomechanical loading of the sacrum endplate due to the gravitational load was computed for the cohort of subjects. The compressive stress magnitude was normalized to the patient weight and personalized by means of the landmarks coordinates from the 3D reconstruction [4]. Mechanical properties of the FEM were derived from literature [4]. Beam elements were used to present the different components of the spine, ribcage and pelvis. Intercostal and intervertebral ligaments were modeled with tension-only spring elements while zygapophyseal joints were modeled using non-linear contact and spring elements. The nodes of the ribcage, pelvis, and vertebrae were interpolated to create the abdominal cavity wall. Later the internal and external structures of the trunk were connected by hedrahexal solid elements [4]. The position of the center of mass of trunk slices at the level of each vertebra was derived from literature and optimized in such a way that the geometry of the spine after application of the gravitational forces resembles the original geometry of the spine [4].

A patient specific osseo-ligamenteous FEM of the spine, ribcage, and pelvis was generated and personalized by means of the landmarks coordinates from the 3D reconstruction [4]. Mechanical properties of the FEM were derived from literature [4]. Beam elements were used to present the different components of the spine, ribcage and pelvis. Intercostal and intervertebral ligaments were modeled with tension-only spring elements while zygapophyseal joints were modeled using non-linear contact and spring elements. The nodes of the ribcage, pelvis, and vertebrae were interpolated to create the abdominal cavity wall. Later the internal and external structures of the trunk were connected by hedrahexal solid elements [4]. The position of the center of mass of trunk slices at the level of each vertebra was derived from literature and optimized in such a way that the geometry of the spine after application of the gravitational forces resembles the original geometry of the spine [4].

Biomechanical loading of the sacrum endplate due to the gravitational load was computed for the cohort of subjects. The compressive stress magnitude was normalized to the patient weight and scaled between the minimum and maximum values of the compressive stress measured on the sacrum endplate in individuals. The barycenter of the compressive stress on the sacrum endplate (COPs1) was calculated by means of the sacrum radius and the magnitude of the compressive stress on the sacrum. The 2D position of the COPs1 in the transverse plane with respect to the center of the hip vertical axis (CHVA) was determined.

A cluster technique (K-means cluster, PAWS statistics 18.0) was used to divide the distributions of compressive stress on the sacrum endplate in two areas i.e. low stress and high stress areas. The position of the low and high stress areas was compared between pre- and post-operative scoliotic groups and controls. The projection of the position
of the COP$S_1$ on the transverse plane with respect to the CHVA was calculated and compared to the position of the center of mass (COM) in the three studied groups.

**RESULTS AND DISCUSSION**

Table 1 shows of the spine and pelvis parameters in the control and pre- and post-operative scoliotic groups i.e. RTs and TL/Ls.

The radiographs and high and low stress areas on the sacrum endplate are shown for one typical RT patient before and 10 months after surgery (Figure 1).

![Figure 1](image)

**Figure 1.** Radiographs and stress distribution on the sacrum endplate before and after surgery in a typical RT subject

Compressive stress on the sacrum was higher at the side of the spinal concavity before operation while the biomechanical loading of the sacrum appears symmetric after operation. No significant different was observed in the position of the COM and COP$_{S1}$ between post-operative and control subjects $p>0.05$ while these parameters were significantly different between pre-operative and controls and pre-operative and post-operative subjects $p<0.05$. The differences between the position of the COM and the COP$_{S1}$ were decreased in post-operative subjects when compared to same parameters before operation.

**CONCLUSIONS**

A patient-specific model of the spine and pelvis used to show the biomechanical impact of the spinal fusion on the sacral loading. Although sacrum remains unfused after spinal operation the results show the possible effect of the spinal fusion on equilibrating the sacral loading in scoliotic subgroups. This effect can be explained by the fact that the position of the center of mass after operation was more similar to the COM position in controls. The results suggest that the position of the COP$_{S1}$ with respect to the position of CHVA and COM can be used as biomechanical parameters to evaluate scoliosis postural parameters pre- and post-operatively.

**REFERENCES**


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