Biomechanical modeling of the interaction between a brace and the trunk in the treatment of scoliosis
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Introduction
Some biomechanical (analytical) models were developed using the finite element (FE) method to simulate brace mechanisms on typical scoliotic patient’s geometry (Andriacchi et al., 1976; Patwardhan et al., 1990; Wynarsky et al., 1991; Aubin et al., 1993, 2000). These studies suggested that a better correction could be obtained but the complex mechanical action of the entire brace on the torso was not completely addressed. Also, very few biomechanical studies were performed on the transmission to the spine of loads applied by an orthosis in the treatment of scoliosis. The aim of this project was to develop an advanced biomechanical model of the trunk and brace to analyze scoliosis treatment.

Methods
The finite element model of the trunk and brace of one patient was build using a 3D geometry obtained from a multiview radiographic reconstruction technique (Aubin et al., 1995). The thoracic and lumbar vertebrae, the intervertebral discs and the rib cage were represented by beam elements. The costo-vertebral and zygapophyseal joints were modeled using contact and multilinear elements. The vertebral and intercostal ligaments were represented by spring elements. Shell and solid elements were used to model the brace and trunk soft tissues. Non-linear point-to-surface contact elements were defined between the brace foam and the torso. The whole model was composed of 5375 elements (with 544 contact elements for the spine and 780 contact elements for the brace-trunk interface) and 3357 nodes (Figure 1). The simulations were defined in two steps: 1) the brace opening and insertion on the patient; 2) the establishment of contact at the brace-torso interface and the brace closing using straps tightening. Material and geometrical non-linearities were taken into account. The boundary conditions were L5 and T1 vertebrae fixed in the sagittal and coronal directions, opening and closing displacements applied to the straps attachment nodes and some anterior brace nodes fixed in the space.

Figure 1: Finite element model of the trunk and brace.

The resulting curves were compared to the in brace patient geometry using position and orientation parameters. The loads (intensity and location) generated at the brace-trunk interface were deduced from pressure measurements performed using 192 thin pressure sensors inserted at the brace-torso interface (Petit et al, 1998), and were compared to the simulation results (contact behavior).
Results
During the brace opening and insertion on the patient, the distance between the straps attachment points increased of 160mm. During the brace closing, the spine curvatures were corrected. The resulting curves did not match the in brace patient curves (Figure 2) because of T1 fixed in its initial position.

![Figure 2: Geometrical curves with and without brace and resulting curves obtained with the new brace modeling in the coronal and sagittal plane (mm), and axial rotations results (°).](image)

At the right thoracic pad location, as measured by the pressure matrix, the nodes were connected to closed contact elements. The contact reaction force (41N) was smaller than the equivalent force (90N) measured by the pressure matrix. At the left thoracic pad location, nearest closed contact elements were distant of 73mm. The contact reaction force (14N) was quite similar to the equivalent force (12N) measured.

Discussion
This model is considered to be an improvement over previous biomechanical models because of the personalized representation of the brace geometry and of the brace-trunk interface. This study carried on one patient demonstrated the feasibility of this new approach that is more realistic than the direct application of forces on the trunk. Current refinements are in progress to integrate contacts between a representation of the abdomen and the brace. With such model, it will be possible to predict the effect of the brace before its design and manufacturing, and also to improve its design.

References
Petit Y. et al., J. Biomech. 31(1),175, 1998.