Spine Deformity
www.spine-deformity.org

Spine Deformity 6 (2018) 344−350

Biomechanics

Surgical Planning and Follow-up of Anterior Vertebral Body Growth Modulation in Pediatric Idiopathic Scoliosis Using a Patient-Specific Finite Element Model Integrating Growth Modulation

Nikita Cobetto, PhD[a,b], Carl-Eric Aubin, PhD, PEng[a,b,*], Stefan Parent, MD, PhD[b]

[a]*Department of Mechanical Engineering, Polytechnique Montréal, P.O. Box 6079, Downtown Station, Montreal, Quebec H3C 3A7, Canada*
[b]*Research Center, Sainte-Justine University Hospital Center, 3175 Côte-Sainte-Catherine Road, Montreal, Quebec H3T 1C5, Canada*

Received 11 August 2017; revised 10 November 2017; accepted 14 November 2017

Abstract

Study Design: Numerical planning and simulation of immediate and post-two-year growth modulation effects of Anterior Vertebral Body Growth Modulation (AVBGM).

Objectives: To develop a planning tool based on a patient-specific finite element model (FEM) of pediatric scoliosis integrating growth to computationally assess the 3D biomechanical effects of AVBGM.

Summary of Background Data: AVBGM is a recently introduced fusionless compression-based approach for pediatric scoliotic patients presenting progressive curves. Surgical planning is mostly empirical, with reported issues including overcorrection (inversion of the side) of the curve and a lack of control on 3D correction.

Methods: Twenty pediatric scoliotic patients instrumented with AVBGM were assessed. An osseoligamentous FEM of the spine, rib cage, and pelvis was generated before surgery using the patient′s 3D reconstruction obtained from calibrated biplanar radiographs. For each case, different scenarios of AVBGM and two years of vertebral growth and growth modulation due to gravitational loads and forces from AVBGM were simulated. Simulated correction indices in the coronal, sagittal, and transverse planes for the retained scenario were computed and a posteriori compared to actual patient′s postoperative and two years' follow-up data.

Results: The simulated immediate postoperative Cobb angles were on average within 3° of that of the actual correction, while it was ±5° for kyphosis/lordosis angles, and ±5° for apical axial rotation. For the simulated 2-year postoperative follow-up, correction results were predicted at ±3° for Cobb angles and ±5° for kyphosis/lordosis angles, ±2% for T1−L5 height, and ±4° for apical axial rotation.

Conclusion: A numeric model simulating immediate and post-two-year effects of AVBGM enabled to assess different implant configurations to support surgical planning.

Level of Evidence: Level III.

Keywords: Anterior vertebral body growth modulation; Idiopathic scoliosis; Finite element modeling; Fusionless; Numerical surgical planning

---

Author disclosures: NC (grants from Natural Sciences and Engineering Research Council of Canada, during the conduct of the study; grants from Canadian Institutes of Health Research, outside the submitted work); CEA (grants from Natural Sciences and Engineering Research Council of Canada, during the conduct of the study; other from Medtronic; grants from Canadian Institutes of Health Research, Natural Sciences and Engineering Research Council of Canada, Canada Research Chair, Zimmer CAS, and Canada First Research Excellence Funds, outside the submitted work); SP (grants from Natural Sciences and Engineering Research Council of Canada, during the conduct of the study; other from Scoliosis Research Society and Canadian Spine Society; personal fees from DePuy Synthes Spine, Medtronic, EOS-Imaging, and K2M; grants from DePuy Synthes Spine, Setting Scoliosis Straight Foundation, Medtronic, EOS-Imaging, Spinologics, Canadian Institutes of Health Research, Canadian Foundation for Innovation, and Natural Sciences and Engineering Council of Canada; personal fees from Fonds de Recherche Québec−Santé; grants from Orthopedic Research and Education Foundation and Rick Hansen Institutes; other from Academic Chair in Pediatric Spinal Deformities of CHU Ste-Justine, outside the submitted work; in addition, SP has a patent Spinologics licensed and stock/stock options with Spinologics).

The engineering analysis and simulation portion within this project were separately funded by the Natural Sciences and Engineering Research Council of Canada (Industrial Research Chair program with Medtronic of Canada) (grant number PCIPJ-346145).

*Corresponding author. NSERC/Medtronic Industrial Research Chair in Spine Biomechanics, Polytechnique Montreal, P.O. Box 6079, Downtown Station, Montreal, Quebec H3C 3A7, Canada. Tel.: (514) 340-4711 ext. 2836; fax: (514) 340-5867.

E-mail address: carl-eric.aubin@polymtl.ca (C.-E. Aubin).

https://doi.org/10.1016/j.jspd.2017.11.006

Introduction

For scoliotic children with remaining growth potential and a progressive deformity, fusionless surgical treatments could be used to correct the spinal deformity while allowing spinal growth [1-3]. A recently introduced compression-based approach called Anterior Vertebral Body Growth Modulation (AVBGM) consists of a spinal instrumentation with vertebral implants linked together by a flexible polypropylene cable applied to the spine anteriorly. This fusionless device is used to apply compressive forces on curve convexity, which intends to modify the pressure distribution on the vertebral epiphyseal growth plates to modulate growth [4]. This instrumentation conceptually allows keeping the intervertebral mobility compared to the standard posterior spine instrumentation and fusion with rods [5]. Like other fusionless treatments, this technique uses the Hueter-Volkmann principle to modulate the growth rate [2,6] (ie, slowing down vertebral body growth rate on the convexity vs. the concavity of the scoliotic curve). A minimally invasive surgical approach can be employed to install the AVBGM device. Moreover, the procedure does not require multiple surgeries [6].

AVBGM has been documented in case reports [7-9], with promising results for skeletally immature patients showing progressive correction of the curve over time [9]. However, difficulties were reported to predict short and long-term postoperative correction [7,8]. Surgical planning is still mostly done empirically to determine the number of instrumented levels and tension in the cable and can be influenced by various parameters such as curve flexibility and unknown remaining growth potential [4,7,8].

Numerical models have been developed to explore different fusionless compression-based devices in human scoliotic spine. These models were used to compare different fusionless compressive devices, to analyze the generated stress redistribution over the growth plates and the ability of these devices to generate growth modulation [5,10,11]. However, such models were not validated with real cases. Also, these models were not personalized to the patient's geometry and were not used for surgical planning.

The objective of this study was to develop and validate a planning tool based on a patient-specific finite element model of pediatric scoliosis integrating growth to computationally predict and assess the immediate and post-two-year 3D biomechanical effects of AVBGM.

Methods

Patient data

The study included 20 pediatric scoliotic patients prospectively and consecutively recruited in the clinical study. Inclusion criteria were a diagnosis of idiopathic scoliosis with progressive curves, an immature skeleton presenting a Risser sign 0 or 1 and a curve magnitude between 40° and 80°. All cases were instrumented with AVBGM by the same orthopedic surgeon. The study was approved by our institutional ethical committee, and each participant and his or her parents gave written consent.

Patient-specific finite element modeling

For each patient, calibrated biplanar posteroanterior (PA) and lateral (LAT) standing radiographs were taken preoperatively using a low-dose digital radiography system (EOS, EOS Imaging, Paris, France). These radiographs were used to build a 3D reconstruction of the patient's spine, rib cage, and pelvis [12,13]. The 3D geometry was used to generate a personalized finite element model (FEM) using Ansys 14.5 software package (Ansys Inc, Canonsburg, PA). The FEM included the thoracic and lumbar vertebrae (T1–L5) (vertebral body, superior and inferior epiphyseal growth plates, and vertebral posterior elements including transverse and spinous processes), as well as the intervertebral discs, ribs, sternum, costal cartilages, pelvis, and ligaments (Fig. 1). The vertebral bodies, epiphyseal growth plates, and intervertebral discs were represented by 3D structural solid elements and posterior vertebral elements, ribs, sternum, costal cartilage, and pelvis by 3D beam elements. The vertebral and intercostal ligaments were represented by 3D tension-only spring elements. The mechanical properties of the anatomical structures were taken from published data obtained on typical human cadaveric spine segments [14-17]. Mechanical properties of the intervertebral discs were calibrated to represent the patient's spinal flexibility by using the right and left lateral bending radiographs. To do so, the right and left lateral shifts of vertebra T1, measured on bending radiographs, were applied, and the intervertebral disc element's stiffness was adjusted such that the left and right lateral bending Cobb angles were adequately simulated within 5°.

The model also included two years of vertebral growth of pediatric spine performed by calculation of the growth response to stresses on growth plates for the considered period of 24 months. The growth calculation process was based on a previously validated algorithm used to study scoliosis pathomechanisms, established on in vivo correlations obtained by growth rates quantification under external forces and relating the actual (σ) and normal physiological stresses (σ_m) [18,19]:

$$G = G_m * (1 - \beta * (\sigma - \sigma_m)) \quad (1)$$

where G is the final longitudinal growth rate, G_m is the baseline growth rate, and β is the bone stress sensitivity factor (G_m was between 0.7 and 0.9 mm/year and β was 1.4 MPa^{-1} at each growth plate) [20]. The algorithm governed by Equation (1) was initiated with spinal loading due to gravitational loading and compressive stresses from the AVBGM, which was used to compute growth response at the epiphyseal growth plates, and was followed by an update of the model geometry. If $\beta*(\sigma - \sigma_m)$ was greater than 1, G was set to 0 to represent a growth arrest.