Spine Deformity
www.spine-deformity.org

Spine Deformity 6 (2018) 507−513

Contribution of Lateral Decubitus Positioning and Cable Tensioning on Immediate Correction in Anterior Vertebral Body Growth Modulation

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Received 10 August 2017; revised 22 December 2017; accepted 29 January 2018

Abstract

Study Design: Computational simulation of lateral decubitus and anterior vertebral body growth modulation (AVBGM).
Objectives: To biomechanically evaluate lateral decubitus and cable tensioning contributions on intra- and postoperative correction.
Summary of Background Data: AVBGM is a compression-based fusionless procedure to treat progressive pediatric scoliosis. During surgery, the patient is positioned in lateral decubitus, which reduces spinal curves. The deformity is further corrected with the application of compression by cable tensioning. Predicting postoperative correction following AVBGM installation remains difficult.
Methods: Twenty pediatric scoliotic patients instrumented with AVBGM were recruited. Three-dimensional (3D) reconstructions obtained from calibrated biplanar radiographs were used to generate a personalized finite element model. Intraoperative lateral decubitus position and installation of AVBGM were simulated to evaluate the intraoperative positioning and cable tensioning (100 / 150 / 200 N) relative contribution on intra- and postoperative correction.
Results: Average Cobb angles prior to surgery were 56° ± 10° (thoracic) and 38° ± 8° (lumbar). Simulated presenting growth plate's stresses were of 0.86 MPa (concave side) and 0.02 MPa (convex side). The simulated lateral decubitus reduced Cobb angles on average by 30% (thoracic) and 18% (lumbar). Cable tensioning supplementary contribution on intraoperative spinal correction was of 15%, 18%, and 24% (thoracic) for 100, 150, and 200 N, respectively. Simulated Cobb angles for the postoperative standing position were 39°, 37°, and 33° (thoracic) and 30°, 29°, and 28° (lumbar), respectively, whereas growth plate's stresses were of 0.54, 0.53, and 0.51 MPa (concave side) and 0.36, 0.53, and 0.68 MPa (convex side) for the three tensions.
Conclusion: The majority of curve correction was achieved by lateral decubitus positioning. The main role of the cable was to apply supplemental periapical correction and secure the intraoperative positioning correction. Increases in cable tensioning furthermore rebalanced initially asymmetric compressive stresses. This study could help improve the design of AVBGM by understanding the contributions of the surgical procedure components to the overall correction achieved.
Level of Evidence: Level III.

Keywords: Anterior Vertebral Body Growth Modulation; Idiopathic scoliosis; Finite element modeling; Lateral decubitus; Fusionless

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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; personal fees from Scoliosis Research Society, Canadian Spine Society, 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; other from Academic Chair in Pediatric Spinal Deformities of CHU Ste-Justine, outside the submitted work; in addition, he has a patent EOS-Imaging with royalties paid 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).

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2212-134X/$ - see front matter © 2018 Scoliosis Research Society. All rights reserved.
https://doi.org/10.1016/j.jspd.2018.01.013

Introduction

For scoliotic children presenting progressive curves and remaining growth potential, recently introduced fusionless approaches are used to control the curve progression during spinal growth [1,2]. A compression-based fusionless device named Anterior Vertebral Body Growth Modulation tether (AVBGM) is aimed to induce vertebral growth modulation while allowing spinal flexibility [3-5]. The AVBGM device involves the instrumentation of the convex side of the curve using vertebral screws attached together by a tethering cable, resulting in compressive forces on the epiphyseal growth plate's convex side [4]. According to the Hueter-Volkmann principle, such compressive forces reduce growth on the convex side as compared to the concave side of the curve [6,7].

During the surgery, the patient is placed in a lateral decubitus position, with the curve convexity pointing upward [4]. The surgical planning for AVBGM installation and correction steps are mostly done empirically [5,8]. Case reports documented immediate postoperative curve correction from 20% to 60%, depending on the curve flexibility and cable tensioning [4]. However, influence of the lateral decubitus on spinal correction and the intraoperative correction needed to generate sufficient growth modulation remain unknown.

Three-dimensional (3D) analysis of the spine using intraoperative 3D radiographic reconstruction showed that intraoperative positioning contributes to correct scoliotic deformities on average by 37% in prone positioning [9] and 44% (between 22% and 71%) in lateral decubitus [10]. Lalonde et al. further simulated spinal changes from the preoperative upright posture to the intraoperative lateral decubitus using a finite element model (FEM) of adolescent idiopathic scoliosis (AIS) [10]. They found that lateral decubitus positioning significantly reduces the thoracic scoliotic curve before surgical instrumentation (44% on average, range between 22% and 71%) [10]. Using an FEM integrating growth dynamics, Driscoll et al. and Clin et al. studied internal stress distributions within intervertebral discs and growth plates of compressive growth modulation devices. Both confirmed their ability to reduce asymmetrical loading on growth plates. Nevertheless, they also outlined the difficulty to factor the different parameters that would enable adjusting the epiphyseal plate's stresses to induce progressive correction with growth [11-13].

The objective of this study was to biomechanically model and analyze the respective contributions of lateral decubitus positioning and cable tensioning on intra- and postoperative correction with AVBGM.

Material and Methods

Twenty consecutive pediatric patients with progressive AIS requiring AVBGM instrumentation were selected. All patients recruited in this study presented two years or more of remaining growth potential (Risser sign 0-1) and Lenke Type 1 curves (primary curves were main thoracic) with a presenting thoracic curve magnitude between 45° and 75°. All procedures performed in this study were approved by our hospital and university ethical research committees. An informed consent was obtained from all individual participants and their parents.

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) (Fig A). These radiographs were used to build a 3D reconstruction of the patient's spine, rib cage, and pelvis [14]. Three-dimensional reconstructions were then used to generate a personalized FEM using the Ansys 14.5 software package (Ansys Inc., Canonsburg, Pennsylvania, PA) (Fig B). Vertebral anterior parts and intervertebral discs were represented by 3D structural solid elements. Vertebral posterior parts, as well as the ribs, sternum, costal cartilages, and pelvis were represented by 3D beam elements. Vertebral and intercostal ligaments were modeled by 3D tension-only spring elements. The mechanical properties of the anatomical structures were based on published data obtained from experimental testing on human cadaveric spine segments [15-18] (Fig B). This FEM was verified and validated for the simulation of AVBGM in a previous study, with reported accuracy within 3°, 5°, and 4° for the simulated immediate and after 2 years postoperative corrections in the coronal, sagittal, and transverse planes [19]. The following indices were computed on the standing preoperative 3D reconstruction using a custom measurement software: thoracic (T) and lumbar (L) Cobb angles, thoracic kyphosis (T4−T12), and lumbar lordosis (L1−L5), as well as thoracic apical rotation.

A suspension test was realized to evaluate the spinal flexibility by relating the patient‘s body weight to the scoliotic curve reduction [20]. Using a harness, patients were suspended by the axillae, until only the toes were touching the floor. A posteroanterior (PA) radiograph was taken and the corresponding thoracic and lumbar Cobb angle reductions were measured. To calibrate the mechanical properties of the FEM intervertebral discs, the suspension test was simulated by applying a downward force representing the patient's weight at the pelvis [21]. The intervertebral disc element's stiffness was adjusted until the simulated thoracic and lumbar Cobb angle reductions reproduced the actual measurements (±5°).

During the surgery, patients were positioned in lateral decubitus, with the curve convexity upward. Cushions were placed under the shoulder blade to protect the brachial plexus, therefore applying corrective forces for the thoracic deformity. A minimally invasive thoracoscopic approach with single lung ventilation was used to install AVBGM through intercostal ports in the midaxillary line [8]. Two intraoperative PA radiographs were taken using C-arm fluoroscopy, before (Fig C) and after AVBGM instrumentation.