Spine Deformity
www.spine-deformity.org

Spine Deformity 4 (2016) 253−260

Biomechanics

Biomechanical Assessment of Providence Nighttime Brace for the Treatment of Adolescent Idiopathic Scoliosis

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Received 27 March 2015; revised 22 December 2015; accepted 24 December 2015

Abstract

Study Design: Biomechanical study of the Providence brace for the treatment of adolescent idiopathic scoliosis (AIS).
Objectives: To model and assess the effectiveness of Providence nighttime brace.
Summary of Background Data: Providence nighttime brace is an alternative to traditional daytime thoracolumbosacral orthosis for the treatment of moderate scoliotic deformities. It applies three-point pressure to reduce scoliotic curves. The biomechanics of the supine position and Providence brace is still poorly understood.
Methods: Eighteen patients with AIS were recruited at our institution. For each patient, a personalized finite element model (FEM) of the trunk was created. The spine, rib cage, and pelvis geometry was acquired using simultaneous biplanar low-dose radiographs (EOS). The trunk surface was acquired using a three-dimensional surface topography scanner. The interior surface of each patient's Providence brace was digitized and used to generate an FEM of the brace. Pressures at the brace/skin interface were measured using pressure sensors, and the average pressure distribution was computed. The standing to supine transition and brace installation were computationally simulated.
Results: Simulated standing to supine position induced an average curve correction of 45% and 48% for thoracic and lumbar curves, while adding the brace resulted in an average correction of 62% and 64% (vs. real in-brace correction of 65% and 70%). Simulated pressures had the same distribution as measured ones. Bending moments on apical vertebrae were mostly annulled by the positioning in the supine position, and further overcorrected on average by 10% to 13%, but in the opposite direction.
Conclusions: The supine position is responsible for the major part of coronal curve correction, while the brace itself plays a complementary role. Bending moments induced by the brace generated a rebalancing of pressure on the growth plates, which could help reduce the asymmetric growth of the vertebrae.
Level of Evidence: Level II.

Keywords: Scoliosis; Nighttime brace; Providence brace; Finite element modeling; Biomechanics

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Author disclosures: AS (grants from Natural Sciences and Engineering Research Council of Canada, from Canadian Institutes of Health Research, during the conduct of the study), JC (grants from Canadian Institutes of Health Research, grants from Natural Sciences and Engineering Research Council of Canada, during the conduct of the study; other from Rodin 4D, outside the submitted work), NC (grants from Natural Sciences and Research Council of Canada, grants from Canadian Institutes of Health Research, during the conduct of the study; other from Lagarrigue [Rodin4D], outside the submitted work), HL (grants from Natural Sciences and Research Council of Canada, grants from Canadian Institutes of Health Research, during the conduct of the study; other from Spinologics, grants from Depuy Synthes, outside the submitted work), C-EA (grants from Natural Sciences and Research Council of Canada, grants from Canadian Institutes of Health Research, during the conduct of the study; other from Groupe Lagarrigue, other from Boston Brace, grants and other from Natural Sciences and Engineering Research Council of Canada; Research Chair program with Medtronic of Canada, outside the submitted work).

Ethical approval: All procedures performed in this study involving human participants were in accordance with the ethical standards of the institutional ethical research committee. Informed consent was obtained from all individual participants included in the study and their parents.

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2212-134X/$ - see front matter © 2016 Scoliosis Research Society.
http://dx.doi.org/10.1016/j.jspd.2015.12.004

Introduction

Adolescent idiopathic scoliosis (AIS) is a complex three-dimensional (3D) deformity of the spine and rib cage. For small and moderate curves (Cobb angle 20 to 45°) with apex below the eighth thoracic vertebra (T8), conservative treatment by thoraco-lumbo-sacral orthoses (TLSOs) is the most common treatment to halt the curve progression until the end of skeletal growth. Bracing significantly decreases the progression of high-risk curves to surgery proportionally with longer hours of brace wear [1], and the risk for curve progression and surgery are reduced in patients with good brace compliance [2,3]. In order to effectively stop scoliotic curve progression, a day-time brace has to be worn more than 12 hours per day [1,4]. Compliance with full-time brace wearing is problematic. Patients wear their braces on average 46% of the time they were instructed to [4]. To overcome this longstanding problem, nighttime braces were developed. Nighttime bracing has less negative effect on psychosocial functioning, sleep disturbance, back pain, body image, and back flexibility [5]. In cases where different braces are equally effective, the recommended treatment would be the brace with the least impact on the quality of life [5].

There are different existing nighttime braces. Among them, the Charleston nighttime brace, introduced in 1978 by Price et al. relies on the principle of side bending to overcorrect the major scoliotic curve [6], and reduced brace wear to a minimum of 8 hours per night during sleep. Providence nighttime brace, introduced by d'Amato et al. in 1992, is based on direct lateral and rotational forces applied at the apex of curves through a three-point pressure system [7]. A CAD/CAM model is made based on the readings of the measurement board [8]. Published clinical studies reported an average initial in-brace correction of 94% for thoracic curves, 111% for thoracolumbar curves, 103% for lumbar curves, and 90% and 91% for double curves, respectively [7,9-11]. Often, overcorrection is observed on supine in-brace radiographs [7]. Overall success rate (curve progression ⩽5° after minimum follow-up of 2 years beyond the cessation of brace wear) is 50% to 75% [7,11]. The recumbent position is also known to reduce the scoliotic curves, in particular during instrumentation surgeries [12,13].

Finite element models (FEMs) were developed to study brace biomechanics and improve the design of braces [14-17]. TLSOs are now simulated with a realistic representation of the contact interface between the patient's trunk and brace [18-20]. Using such approach, it was possible to quantify Charleston brace's biomechanical effects, such as the inversion of asymmetrical compressive loading in the major scoliotic curve, and the worsening of compressive loading in the compensatory curves [21]. The finite element modeling of daytime braces was also extensively done to assess the biomechanics of braces [17-22] and improve their design [20,23], as well as to study the effect of recumbent positioning [24]. In a recent ongoing randomized clinical trial, preliminary results of 40 patients showed that a novel design scheme combining CAD/CAM and 3D FEM simulation allowed the fabrication of more efficient and lighter braces compared to the use of CAD/CAM only [25].

Although Providence brace has been available for more than 20 years, the biomechanics of this treatment as well as the specific effects of brace design parameters and of the recumbent position are still not well described. The CAD/CAM model is chosen from a brace data bank based on mold inventory [8], then subjected to derotation of the thoracic section. The impact of brace design and adjustments on outcomes are not well understood, as no evaluation method is used before brace fabrication. The objective of this study was therefore to biomechanically model and assess the Providence nighttime brace for the treatment of AIS in order to better understand its mode of action.

Materials and Methods

Patient data

Inclusion criteria were diagnosis of AIS by the treating orthopedic surgeon, age 10−16 years at time of Providence brace prescription, thoracic and/or lumbar curve Cobb angle 20−45 degrees, and first time or renewal brace. Exclusion criteria were non-idiopathic scoliosis and previous spine surgery.

Patient and brace FEMs

For each case, the internal osseous anatomy (spine, rib cage, and pelvis) was reconstructed in 3D using a simultaneous biplanar low-dose system (EOS imaging SA, Paris, France) [26,27]. The accuracy of this technique is 1.0 mm for the spine and pelvis and 1.9 mm for the rib cage [26,27]. A free-form interpolation technique was used to generate a detailed 3D model of the spine, pelvis, and rib cage based on anatomic reference points. The external geometry (skin surface) of the trunk was acquired using a 3D surface topography technique (3-dimensional Capturor; Creaform Inc., Lévis, Canada) [28]. Internal and external geometries were registered by applying a point-to-point least square algorithm to 12 radiopaque markers attached to anatomic landmarks on the patient's torso [29].

A personalized FEM of each patient's trunk was then created using ANSYS 14.5 software package (ANSYS Inc., Canonsburg, PA, USA) by methods previously validated [21]. This model includes the thoracic and lumbar vertebrae, intervertebral discs, ribs, sternum, costal cartilages, abdominal cavity, and pelvis, which were represented by 3D elastic beam elements. The zygapophyseal joints were modeled by shells and contact elements, the vertebral and intercostal ligaments by tension-only spring elements, and