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The Use of Finite Element Models to Assist Understanding and Treatment For Scoliosis: A Review Paper

Wenhai Wang, PhD[a,*], George R. Baran, PhD[a], Randal R. Betz, MD[b], Amer F. Samdani, MD[b], Joshua M. Pahys, MD[b], Patrick J. Cahill, MD[b]

[a]College of Engineering, Temple University, 1947 North 12th Street, Philadelphia, PA 19122, USA

[b]Shriners Hospitals for Children–Philadelphia, 3551 North Broad Street, Philadelphia, PA 19140, USA

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Abstract

Introduction: Scoliosis is a complex spinal deformity whose etiology is still unknown, and its treatment presents many challenges. Finite element modeling (FEM) is one of the analytical techniques that has been used to elucidate the mechanism of scoliosis and the effects of various treatments.

Methods: A literature review on the application of FEM in scoliosis evaluation and treatment has been undertaken. A literature search was performed in each of three major electronic databases (Google Scholar, Web of Science, and Ovid) using the key words ‘‘scoliosis’’ and ‘‘finite element methods/model’’. Articles using FEM and having a potential impact on clinical practice were included.

Results: A total of 132 abstracts were retrieved. The query returned 105 articles in which the abstracts appeared to correspond to this review’s focus, and 85 papers were retained. The current state of the art of FEM related to the biomechanical analysis of scoliosis is discussed in 4 sections: the etiology of adolescent idiopathic scoliosis, brace treatment, instrumentation treatment, and sensitivity studies of FEM. The limitations of FEM and suggested future work are also discussed.

Keywords: Adolescent idiopathic scoliosis; Etiology; Brace treatment; Surgical treatment; Clinical biomechanics

Introduction

Scoliosis is a 3-dimensional deformity of the spine and rib cage, and has a prevalence of 2% to 4% in adolescents [1,2]. The deformity involves a lateral deviation of the spine from the midline in the coronal (frontal) plane, rotation in the axial plane, and decreased curvature in the thoracic area in the sagittal (side) plane (Fig. 1). Adolescent idiopathic scoliosis (AIS) is the most common spinal deformity, accounting for more than 80% of idiopathic scoliosis cases [3]. Current treatment paradigms for scoliosis (juvenile scoliosis and AIS) are guided by the medical devices available and are based largely on the surgeon’s experience. Wide variations exist in the surgical decision making surrounding the treatment of scoliosis [4]. There is a need for patient-specific modeling tools that can help surgeons plan surgical interventions and optimize treatment outcomes in individual patients [5]. To study scoliosis pathomechanics and treatments, it is important not only to assess the geometric deformity, but also to analyze the material properties and stresses within the spine [6].

Finite element modeling (FEM) in conjunction with experimental techniques has been used in spine research for nearly a half century [7]. (See Appendix for terminology.) In FEM, a structure (eg, the vertebrae) can be divided into a collection of subdomains. Each subdomain can be represented by a finite number of elements that are interconnected with shared nodes. The advantage of this method is that it can

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*Corresponding author. College of Engineering, Temple University, 1947 North 12th Street, Philadelphia, PA 19122, USA. Tel.: (215) 204-6233; fax: (215) 204-4956.

E-mail address: seawangnj@gmail.com (W. Wang).

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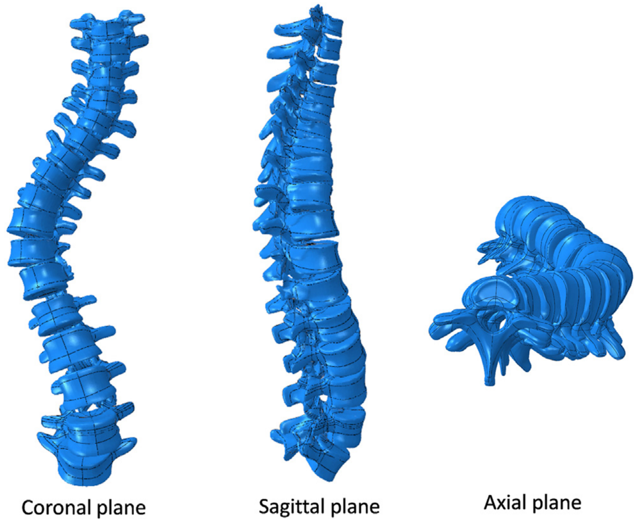

Fig. 1. Spine with scoliosis.

accurately represent complex geometry. It can also include dissimilar material properties. Different types of analysis (eg, static, dynamic) can be performed. Information such as stress and strain that otherwise cannot be measured experimentally can be obtained from these analyses. A series of different FEMs have been used to study outcomes of scoliosis surgery with different implants, the etiology of scoliosis and biomechanics of scoliosis progression, and the biomechanics of bracing. Biomechanical simulation of the surgical correction of the scoliotic spine can provide practical guidelines for different corrective techniques in terms of force level and fixation sites [8]. Finite element modeling can also improve our understanding of the mechanism of development of scoliosis from a mechanical point of view [9]. To the best of our knowledge, there is no such review of FEMs available that covers these topics.

The objectives of this review article were to provide an overview of the use of FEM in scoliosis biomechanics research, discuss the limitation of current FEMs, and suggest future work. The second section briefly introduces the different types of FEM used in the study of scoliosis; application of these models, including the etiology, brace treatment, instrumentation treatment, and sensitivity studies of the models are discussed in the third section. The next section discusses more technical details of the models, such as the geometric reconstruction techniques, components, and material properties. The final section presents a summary and recommendations for future work.

Materials and Methods

The literature search was performed in 3 major electronic databases, Google Scholar, Web of Science, and Ovid, using the keywords "scoliosis" and "finite element method/model." The entire content of all selected articles was thoroughly analyzed. Only articles using FEM and having a potential impact on clinical practice were included. Although they are widely used as a tool for biomechanical studies of scoliosis, kinematic models [10-12] were not included for the sake of defining a focused scope of discussion appropriate for a single article. The use of kinematic models in scoliosis research is a topic that likely would benefit from a separate review of similar length and depth as this article.

A total of 132 abstracts were retrieved using the selected keywords. The primary author analyzed the full content of 105 articles returned by the query in which the abstracts appeared to correspond to this review's focus, and 85 papers were retained. Most of the studies can be categorized into 4 groups: the etiology of AIS, brace treatment for moderate deformities, instrumentation treatment for severe deformities, and sensitivity studies of FEM.

The researchers divided the FEM used in scoliosis research into 4 groups based on model complexity: representative

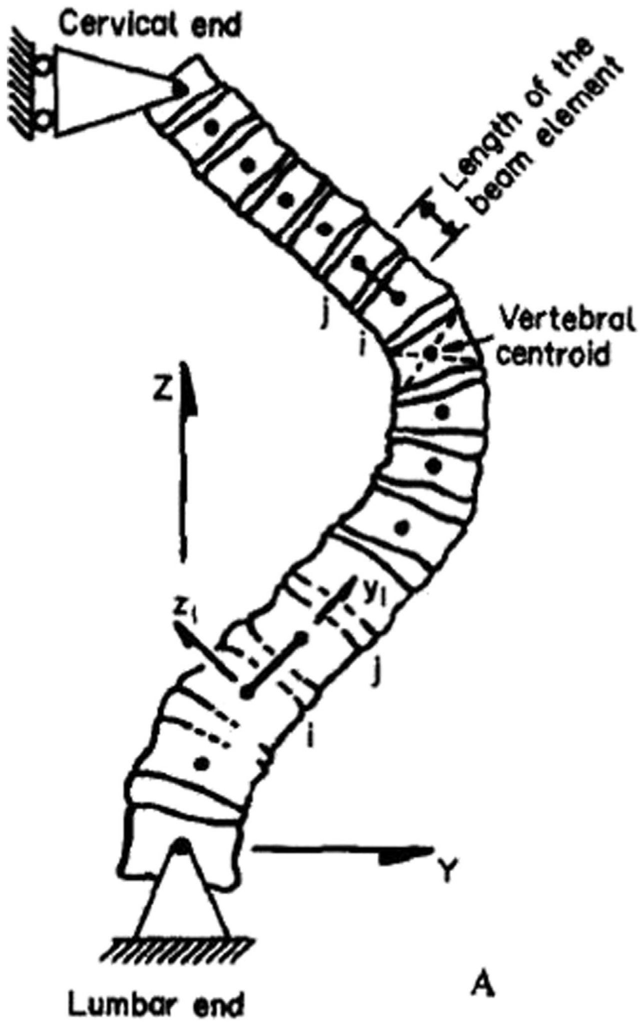

Fig. 2. Representative simple version of beam element–based finite element model. Motion segment is represented by a beam element. Reprinted from *Journal of Biomechanics*, Vol. 21, Ghista DN, Viviani GR, Subharaj K, et al. Biomechanical basis of optimal scoliosis surgical-correction. Page 78, 1988, with permission from Elsevier.