Development of a Congenital Early Onset Scoliosis Finite Element Model

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Disclosures: Hannah McGinty – None, Sriram Balasubramanian – None, Patrick J. Cahill, MD - None

INTRODUCTION:
Early Onset Scoliosis (EOS) is a progressive spine and ribcage deformity that affects children under 10 years of age. EOS is a heterogeneous deformity which can be caused due to reasons such as congenital birth defects, neuromuscular conditions, and other syndrome related reasons. Due to heterogeneity of deformity, there is limited consensus among clinicians regarding surgical treatment options. Patient-specific Finite Element (FE) modeling is a useful tool to simulate various intervention. This study aims to create a three-dimensional (3D) hexahedral FE model of the osteo-ligamentous thoracic and lumbar spine and ribs of a congenital EOS patient.

METHODS:
After Institutional Review Board approval, computed tomography (CT) scan of a four-year-old female congenital EOS patient were acquired from the Children's Hospital of Philadelphia. 3D geometries of the thoracic and lumbar vertebrae, and ribs were reconstructed using 3D Slicer (Slicer 4.11). The geometries were then meshed with hexahedral elements using Ansys ICEM CFD 2022R2 (Ansys, PA). Spinal Ligaments and intervertebral discs (IVDs) were added to the meshed model using HyperMesh 2021.2 (Altair Inc, MI). Seven spinal ligaments namely ligamentum flavum, intertransverse ligament, facet capsulary ligament, posterior longitudinal ligament, interspinous ligament, anterior longitudinal ligament, and supraspinous ligament were modeled as 1D spring elements. Jacobian (>0.5), warpage (<50), skewness (<60), and aspect ratio (<5) were used as acceptance criteria for high-quality hexahedral elements [2].

RESULTS:
The FE model consisting of thoracic and lumbar vertebrae with IVDs and ribs comprised a total of 165,901 hexahedral elements (Figure 1). The model met all the criteria for acceptable mesh quality.

DISCUSSION:
This is the first study to develop a comprehensive hexahedral FE model of the thoracic and lumbar (T1-L5) spine including ribs of a four-year old congenital EOS subject. While previous EOS FE models have used tetrahedral elements, they display undesirable effects such as shear, volumetric locking and increased stiffness [1]. Although more time consuming to create, hexahedral elements used in the current model provide solutions with greater accuracy and faster convergence rates.

SIGNIFICANCE/CLINICAL RELEVANCE:
The current FE model can serve as a template to create congenital EOS patient-specific models. Furthermore, growth and surgical procedures can be simulated using such models to guide surgical planning.

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ACKNOWLEDGEMENTS:

We would like to thank the Wyss-Campbell Center for Thoracic Insufficiency Syndrome at CHOP and STAR Scholar program at Drexel University for providing funding support. We thank Manav Divekar and Girish Viraraghavan for their guidance and support in model development.

IMAGES:

Figure 1. (A) Anterior and (B) Posterior views of the Hexahedral FE model with thoracic and lumbar spine and ribs of a four YO congenital EOS subject.