Title: Artificial Intelligence Data-driven Model for Adolescent Idiopathic Scoliosis: Analysis, Prediction and Treatment

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Title of Grant: Modeling and Analysis of Material Transport in Complex Geometry of Neurons

Abstract Authors:

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Abstract Text:

Scoliosis, a 3D deformation of the human spinal column, is characterized by a lateral deviation of the spine accompanied by axial rotation of the vertebra. In this proposal, the primary focus is on Adolescent Idiopathic Scoliosis (AIS), the most common type of scoliosis affecting children between ages 10 to 18 when bone growth is at its maximum rate. The treatment of scoliosis is highly dependent on the scoliosis curvature type. Currently, the selection of the most appropriate treatment option is based on the surgeon's experience as there is a paucity of a reliable predictive method for progression of curvature in scoliosis spine. Therefore, developing a clinically validated, patient-specific, real-time predictive model of the spine is expected to aid the surgeons in understanding AIS in its early stages, monitoring the curve progression, and proposing an efficient method of treatment for individual patients.

This proposed project has four major thrusts: 1) Automatic generation of spine's CAD model from medical images including X-ray and MRI, 2) Developing a clinically validated patient-specific Reduced-Order Finite Element Model (ROFEM) of the spine, 3) Predicting AIS progression in real-time using data mining, and 4) Proposing an efficient method of treatment.

Generating patient-specific and accurate computational models of the spine from X-ray images is a challenging and time-consuming problem. We aim to develop an automatic framework for creating **patient-specific** models of the spine from 2D X-ray images and a template spine geometry. To accomplish this task, image segmentation of the vertebra will be performed in the anteroposterior and lateral X-rays using **a novel B-spline based algorithm**. The landmarks or corner points of the vertebrae will be extracted from the 2D template and the patient-specific images. Later, the landmarks will be reconstructed in 3D space and integrated into the landmark-based deformable registration framework. This framework will use higher-order B-splines to evaluate the deformation field and thus will be suitable to capture large and complex changes within images. The implementation of this technique will make the framework robust for large variations in the patient-specific shapes. Finally, the deformation field will be applied on the

template mesh to create patient-specific spine geometry from 2D X-ray images of lumbar and thoracic spine. We also plan to work on the automatic partitioning of the registered vertebra model into the growth plate and cortical bone to study bone growth more accurately from the computational models.

The second thrust centers around creating a reduced-order FE model of spine using available spine's CAD model generated from surface registration method in thrust one. Since the longitudinal growth of long bones and vertebrae occurs in cartilaginous growth plates, in this study the progressive growth will be applied to these plates using a conceptual model corresponding to the biological process of long bone growth. The material properties of different parts will be updated dynamically which is a significant novelty of the proposed methodology. Moreover, research has shown that AIS is associated with low bone mass density [2]. The developed FE model can incorporate this effect of bone mineral density (BMD) on the curve progression.

In the off-line stage, the displacement field is solved for the whole model for different configurations of the spine corresponding to different stages of the disease. Later, Morphing transformation is used to chase the displacement vector of consistent points among different configurations. Morphing is a transformation of one shape to another by gradually distorting the first shape so as to move certain chosen points to the intended position to conceive the required shape. Proper orthogonal decomposition (POD) will be used to find the principal directions of the displacement field for the same nodes within different configurations.

In the on-line stage, the stress field will be calculated using the displacement field for the current configuration obtained through the POD basis vectors from the off-line stage. This stress field and the data obtained from X-ray images will be fed to the neural network to predict the curvature for the next time step.

For fast and real-time prediction (thrust three), a system of physics guided neural network (PGNN) will be trained to predict the new positions of landmarks that consider the physics of bone growth. The generated CAD model from image segmentation developed in thrust one will be updated based on the results obtained by this neural network, mesh morphing technique will be used to update the geometry, and the developed ROFEM is used to calculate the stress field of some certain region and pass the data to the PGNN.

In our final thrust, an automatic self-learning algorithm will be trained to give treatment path suggestions. The function of a brace and correcting rods is to apply the force to a patient's spine to correct scoliosis. A good treatment path will suggest different brace designs or correcting rods at different stages of the treatment period. The proposed self-learning algorithm will give real-time design suggestions according to the time-history data and current curvature. The methodology we use is modified reinforcement learning. However, this requires a quick calculation for each step with each action. The real-time prediction can be reached by using the generated neural network.

The anticipated outcome of the proposed work is a general, predictive, patient-specific, computational model of the human spine, taking into consideration detailed parts of the spine, including the vertebral body, intervertebral discs, and growth plates. The project builds on data-driven principles within mechanics with the potential for investigating other spinal deformities such as kyphosis, lordosis and similar diseases caused by spinal rotation such as neural foraminal stenosis. This will enable surgeons to design a treatment plan focusing on the critical parts of the spine, which control the curvature. Our ongoing experimental and computational efforts can provide the best possible treatment method based on the initial scoliosis evaluation appointment.