DEVELOPMENT AND VALIDATION OF A PEDIATRIC HEAD AND NECK MUSCULOSKELETAL MODEL

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INTRODUCTION
Neuromuscular control of the head and neck is essential for daily activities and prevention of injury. Understanding dynamic control of the pediatric neck musculoskeletal system enables us to address injury biomechanics in children as well as aid children with neuromuscular disabilities. Maturation of the head and neck involves complex changes in relative head size, ligament elasticity, as well as orientation of the facets and vertebral bone density. These changes make younger children (< 8 y.o.) twice as likely to sustain serious spinal injuries compared with their older counterparts (9-16 y.o.) [1]. Motor accidents are the most common cause of spinal injury to younger children, 72% of which are cervical spine injuries [2].

In spite of the need to understand neck musculoskeletal control for injury prevention, there exists no validated head and neck musculoskeletal model. The objective of this study was to develop an anatomically and biomechanically accurate musculoskeletal model of the pediatric head and neck, then validate its kinematics and muscle activation response.

METHODS
Our pediatric model was designed after the adult musculoskeletal spine model by Vasavada et al. [3] using the OpenSim (v.2.0.2) platform. The pediatric model was scaled specific to the six year old male by adjusting the following parameters: anatomical dimensions, mass properties, moments of inertia, maximum isometric muscle force, and tendon slack length.

Anatomic scaling of the bones was performed based upon anthropomorphic data [4] (Figure 1). Each bone was linearly scaled in three dimensions using the averages of vertebral body height, sagittal length, and coronal length. Neck length data were used to transform each vertebra to its new position. Next, pediatric vertebral mass properties were ascribed based on from Lowrance’s study of adult vertebral mass [5]. The head and vertebral moments of inertia were calculated from mass and geometry:

\[ I_{axes} = I_{cg} + m_{segment}r_{axes}^2 \]

In addition to anatomically scaling the adult spine model, the muscle properties were also scaled to reflect the developing pediatric musculoskeletal system. The muscles were categorized into three groups: (1) flexion, (2) extension, and (3) lateral bending. In each direction of bending, the maximum isometric force (as a percent of adult) was measured in a healthy sample [7]. This age based percentage was then applied to each individual muscle in that respective group. Tendon slack length in children is longer relative to muscle length compared with adults and was scaled down for the pediatric model based on calculations from O’Brien et al [8].

Finally the pediatric model range of motion was defined based on human subject data for 6 y.o. males where sagittal plane motion was -60.3° (flexion) to 77.2° (extension), coronal plane motion equalled -51.0° to 51.0°, and transverse plane rotation was -74.0° to 78.0° [9].
Model stability and validity were evaluated using the Static Optimization tool in OpenSim. Pediatric neck EMG data (n=9) was further used to validate the model's muscle response to flexion/extension activities.

RESULTS AND DISCUSSION

Muscle output for the model was generated using the Static Optimization tool in OpenSim. The model was stable in Static Optimization and generated real muscle forces. These forces and activation patterns of the sternocleidomastoid, trapezius, and splenius capitis muscle groups were plotted over the range of motion for flexion/extension. The muscle activation was computed using singular spectral analysis to distinguish time periods in which the muscle was ‘on’ versus ‘off’ (Figure 2).

Assumptions and limitations of the OpenSim pediatric model include right/left symmetry, three degrees of freedom, assuming the TSL scaling factor is the same for all muscle groups as well as assuming that superficial and deep muscle properties are scaled alike. Based on an extensive literature search these assumptions provide for the most accurate model to date in the absence of more data. Currently the model is validated for static optimization of flexion/extension, but future plans include multi-axial static and dynamic validation.

This is the first pediatric musculoskeletal model which is stable and validated for kinematics, muscle forces, and muscle activation from pediatric human subject data. The musculoskeletal model's similar patterns of muscle force and activation make it a valuable tool to understand pediatric neck control.

CONCLUSIONS

An anatomically accurate pediatric (6 y.o.) head and neck musculoskeletal model was developed and validated for flexion/extension kinematics and muscle response. This model will lead the way in characterizing the unique head and neck biomechanics specific to the pediatric population and potentially aid in injury prevention in children.

REFERENCES


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