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THE INFLUENCE OF MUSCLE MODELING METHODS AND PATHS ON HEAD AND NECK RESPONSE

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For inertial loading in frontal impacts, the effects of the neck muscles are profound[1]. Computational models using finite element and multibody dynamics have shown that the most important modeling parameters dictating head kinematics are the muscle constitutive properties, muscle locations, muscle line-of-action, the activation levels, and the activation timing[2-6]. A tensed muscle response may contribute 40% or more of the compressive tolerance of the adult and pediatric neck[1]. For these reasons, improving the accuracy of both muscle geometries and kinematics constitutive properties represents an opportunity to enhance overall model performance. The objective of the current study was to evaluate techniques for modeling muscle curvature in adult computational neck muscles using data from cadaveric dissections and MRI, and to investigate the changes in overall head/neck response when using different muscle wrapping techniques.

The computational head and neck models used in the current study are based on prior research and consists of an osteoligamentous cervical spine and head, as well 22 cervical spine muscles, split into 81 muscle strands to span their broad origins and insertions. Each muscle strand was modeled with two parallel rate sensitive beam elements to capture the active and passive muscle behaviors. Model simulations were performed using the general-purpose multiphysics simulations software LS-DYNA (LSTC, Livermore, CA).

Muscle paths were developed through a weighted average of muscle strand pathways based on physiological cross-sectional area from previously published cadaveric data[7,8]. Pathways were compared MRI derived spinal muscle paths from Vasavada et al. (2008). To investigate the effect of wrapping, three muscle models (Figure 1) were implemented to simulate the interactions of muscle, vertebra, and other soft tissue during bending. These were: 1. single-segment muscles with interactions between the muscle and the osteoligamentous spine only at the muscle origin and insertion locations, 2. multi-segment muscles, with muscles divided serially into segments and 3. multi-segment muscles with a sliding contact interaction between the muscles and the vertebrae.

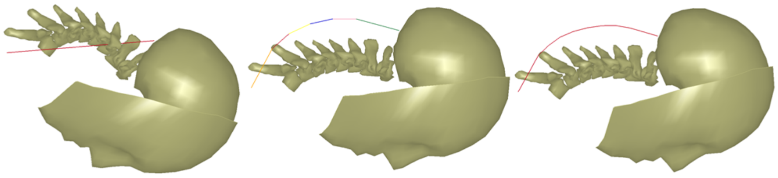

Fig 1. Single-segment (left), multi-segment (center), and sliding contact (right) muscle in a flexed position.

Two loading conditions were investigated. The first loading condition was an adult volunteer 15 G frontal impact performed at the Naval Biodynamics Laboratory[10,11]. The second loading condition was a pendulum calibration test used to certify new Hybrid III ATD necks prior to testing in frontal impact loading scenarios (49 CFR 527, Subpart E). Two activation states were simulated: 1. A relaxed state representing an unaware subject, and 2. Full extensor activation, representing the maximum possible resistance to flexion.

Muscle paths derived from cadaveric dissections and modeled using multiple linear muscle strands resulted in curved loading lines of action similar to the MRI derived muscle paths from Vasavada et al. (2008). Six of the 12 muscles had a portion of their paths, (on average 25±14% of the path length), that were significantly different ($p<0.05$) from the MRI derived paths (i.e., the corridor did not include the MRI path). A comparison of the three muscle wrapping techniques to the volunteer corridor (Table 1) showed both multi-segment and sliding contact models provide greater correlation with the volunteer responses than the single-segment model, with the sliding contact model with full extensor activation providing the highest correlation.

Table 1. Comparison of average global correlation score by muscle activation and muscle wrapping technique.

Muscle Wrapping Technique	Activation	
	Full Extensor	Relaxed
Single-Segment	0.712	0.696
Multi-Segment	0.823	0.709
Sliding Contact	0.863	0.721

Modeling anatomically correct cervical muscle lines of action and attachments was possible by segmenting each muscle into numerous linear strands. Additionally, muscles that incorporated muscle wrapping with sliding contact interactions resulted in the highest correlation to volunteer kinematic corridors in a 15 G frontal impact. This curvilinear muscle response is important in tensile, compressive, and bending modes of loading, and should be included to improve model response for frontal impact with muscle activation.

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