Kinematic Analysis of the Cervical Spine: An Evaluation of Updated Constraints of a Musculoskeletal Model

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Summary

The Musculoskeletal model for the Analysis of Spinal Injury (MASI) and its applicability in analyzing the cervical spine was investigated in this work. The model's kinematic results were evaluated with a focus on the various cervical spine joints and their range of motion. The MASI model was found to have limitations in the range of motion of the cervical spine joints, which were adjusted to align with anatomical values. These adjustments provide more representative results.

Introduction

Excessive load on the cervical spine can lead to injury and degeneration of the vertebrae, intervertebral discs, and supporting structures [1,2]. Musculoskeletal modeling is a powerful tool in analyzing cervical spine loading [3]. However, during the initial evaluation of these models, it became evident that the ranges of motion for cervical spine joints were set smaller than their anatomical ranges [4]. Modeling limitations due to restricted joint ranges were addressed by testing alternative constraints.

Methods

Motion data of flexion/extension, lateral flexion, and rotation of the head and neck were obtained from 15 male subjects (age: 26 ± 3 years, body height: 182 ± 5 cm, body mass: 79 ± 6 kg). The marker set was comprised of 18 retroreflective markers, with ø 19 mm. Six markers were positioned on the torso, two on the temporomandibular joints and 10 on a head frame [1]. The subjects were asked to perform all movements to a comfortable maximum.

Table 1: Constraints of the three models.

	Original Constraints	Representative Constraints	Maximum Constraints
Pitch 1	−16° to 24°	−23° to 23°	−54° to 54°
Pitch 2	−33° to 48°	−75° to 75°	−180° to 180°
Roll 1	−6° to 6°	−8° to 8°	−14° to 14°
Roll 2	−33° to 33°	−51° to 51°	−101° to 101°
Yaw 1	−27° to 27°	−47° to 47°	−58° to 58°
Yaw 2	−38° to 38°	−59° to 59°	−144° to 144°

Pitch 1, Roll 1, and Yaw 1 describe the flexion/extension, lateral flexion, and rotation of the cervical spine from the head to C2, while Pitch 2, Roll 2, and Yaw 2 describe the movement from C2 to T1.

The Musculoskeletal model for the Analysis of Spinal Injury (MASI) [5] was analyzed using OpenSim (v4.4) [4]. The model simulates cervical spine movement across two joints, one located at C1-C2 (represents the movement between the head and C2) and C7-T1 (represents the movement between C2 and T1). Two additional versions of the MASI model were created with joint constraints derived from literature values [4] (Table 1). Inverse kinematics were calculated with all three models using the motion data. The maximum summed joint angles of each movement were tested for normality using the Shapiro-Wilk test; a one-way repeated measures ANOVA, followed by Tukey's post-hoc analyses, which were conducted in GraphPad Prism (v10.4.1) with $\alpha = 0.05$.

Results and Discussion

In all movements, the MASI model with representative and maximum constraints delivers significantly higher angles in comparison to the model with original constraints (Figure 1). The models with representative and maximum constraints allow greater angles, thus, they presumably support a more accurate simulation of the full range of motion of the cervical spine.

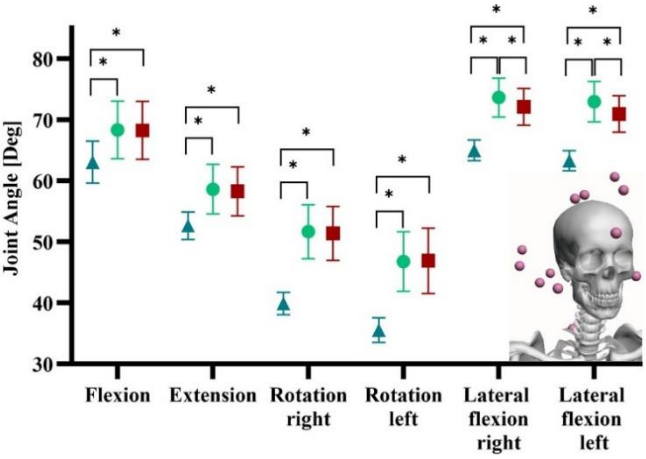

Figure 1: Mean and 95% confidence intervals of the maximum joint angles for each model. ▲: original, ●: representative, and ■: maximum constraints. *$p < 0.05$

Conclusions

When analyzing the full anatomical range of motion, the default model constraints prove to provide an insufficient range of motion. With incorporation of the representative and maximum constraints, the MASI model offers a more representative simulation of the entire range of motion of the cervical spine.

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