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# Cervical spine intervertebral kinematics estimated from inverse kinematics and compared to dynamic X-ray data

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## 1. Introduction

Spine modeling is challenging because the positions of each vertebra cannot be known from external measurements, and a relationship must be assumed between external and intervertebral kinematics. We have previously found that the predictions of biomechanical models are influenced by these assumptions [1,2], but intervertebral kinematics have not been estimated with an inverse kinematics solver and compared to dynamic X-ray data.

## 2. Research question

This study addressed how different kinematic assumptions affect the prediction of intervertebral kinematics from external markers, and how the predicted kinematics compare to radiographic measurements.

## 3. Methods

Twenty-nine subjects executed head-neck extension/flexion motion in a seated posture. Kinematics of the head and trunk were recorded by a 12-camera motion capture system (Vicon MX, Oxford, UK, 60 Hz) with five surface markers on the head and five on the trunk. Biplanar dynamic radiographic data (70 KV, 160 mA, 2.5 ms X-ray pulses, 30 Hz) were collected simultaneously to determine vertebral motions [3]. A generic head and neck model [4] in OpenSim [5] was scaled by marker data for one subject. An inverse kinematics solver was used to estimate joint kinematics by minimizing the error of the tracked external markers. Intervertebral motion was assumed to act as a hinge joint, with fixed centers of rotation [6]. Three models differed according to the number of independent degrees of freedom (DOF) between the head and trunk. In the 3DOF model, the amount of rotation at each intervertebral joint is a fixed percentage of the total angular motion between the skull and T1. In the 6DOF model, the rotation at each joint is dependent on both head and neck angle. In the 24DOF model, the amount of rotation at each joint is not constrained. Intervertebral kinematics were calculated at each cervical level and compared to dynamic X-ray data using the mean value of the absolute differences.

## 4. Results

Error varied with model type and vertebral level. The 24DOF model had lowest error for C1-C5 but largest for C5-C7. At the C4/C5 joint, average differences between each model and *in vivo* kinematics were $2.52^{\circ}\pm1.29^{\circ}$, $3.62^{\circ}\pm1.92^{\circ}$, and $2.20^{\circ}\pm1.26^{\circ}$ for 3DOF, 6DOF, and 24DOF models respectively (Fig. 1).

## 5. Discussion

This study provides valuable data comparing different assumptions about segmental contributions to intervertebral kinematics. However, there is room for improvement in estimating intervertebral motion from external markers. Other kinematic variables, such as intervertebral translations, may be important for accurate prediction of intervertebral motion.

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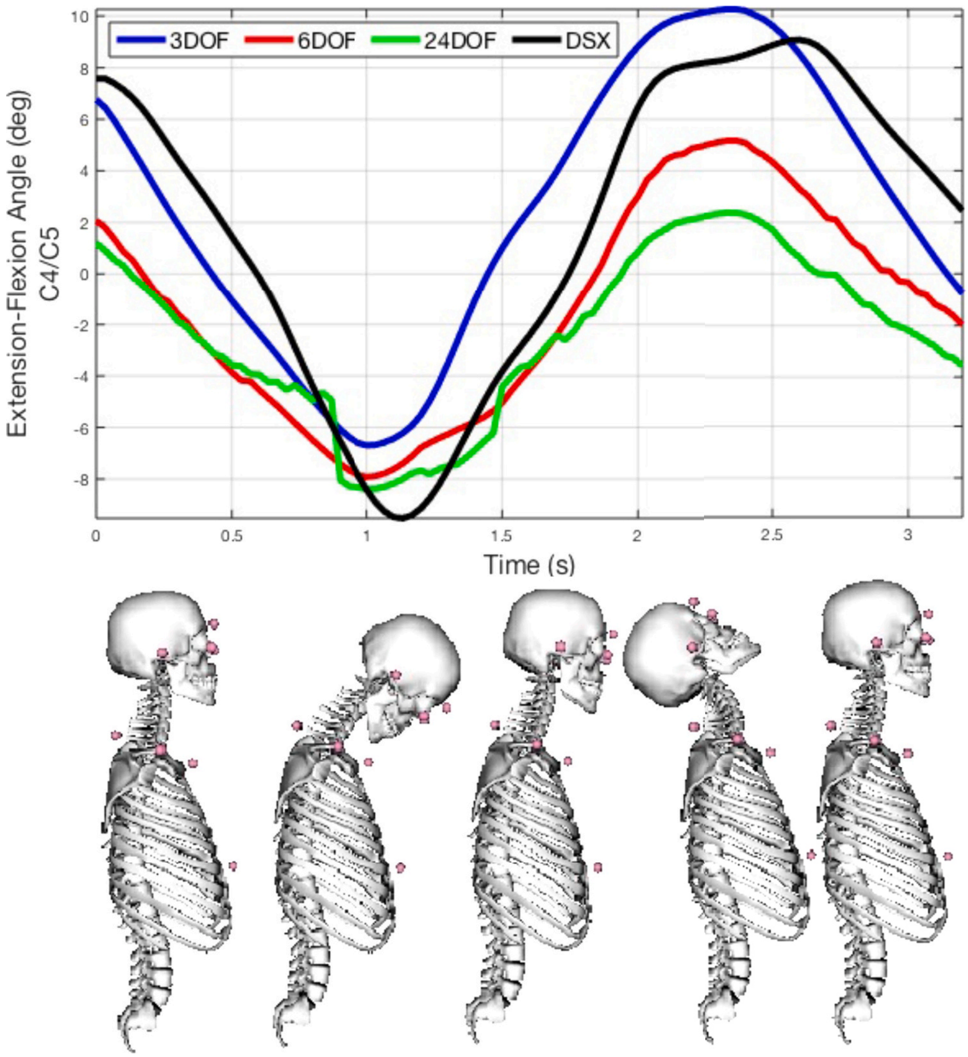


**Fig. 1.** The extension-flexion angles of the C4/C5 joint for one subject. The blue, red, and green lines indicate the 3DOF, 6DOF, and 24DOF model outputs, respectively, while the black line indicates the *in vivo* measurements from biplanar dynamic X-ray. Positive angle is flexion, and negative angle is extension (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article).

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