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Cervical motion segment contributions to head motion during flexion\extension, lateral bending, and axial rotation

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Abstract

BACKGROUND CONTEXT: Cervical spine segmental contributions to motion may reveal movement abnormalities associated with whiplash, disc herniation, disc arthroplasty, or fusion.

PURPOSE: The objective of this study was to determine the cervical spine segmental contributions to head flexion\extension, lateral bending, and axial rotation during dynamic motion in young, healthy individuals.

STUDY DESIGN: The study design was a descriptive control study.

PATIENT SAMPLE: Twenty-nine young (20–35 years of age) healthy individuals comprised the patient sample.

OUTCOME MEASURES: Physiologic measures of contributions from each cervical motion segment to the primary head rotation were the outcome measures for this study.

METHODS: Twenty-nine healthy participants performed full range of motion (ROM) flexion\extension, lateral bending, and axial rotation while biplane radiographs were collected at 30 images per second. Surface-based markers were used to determine head kinematics for each movement, and a validated volumetric model-based tracking technique was used to determine intervertebral kinematics. Contributions from each cervical motion segment to the primary head rotation were determined continuously during each of the three head movements. This study was funded by Synthes Spine (F).

RESULTS: For each head movement, motion segments in the lower cervical spine increased their contributions to head motion near the end of the ROM. Cervical motion segment contributions to left and right lateral bending were mirror images of each other, as were contributions to left and right axial rotation. However, cervical motion segment contributions to flexion were not mirror images of the contributions to extension.

CONCLUSIONS: Cervical motion segment contributions to head motion change over the full ROM and cannot be accurately characterized solely from endpoint data. The continuously changing segmental contributions suggest that the compressive and shear loads applied to each motion segment also change over the ROM. The clinical implication of increased contributions from the inferior motions segments near the end ROM is that the clinician may advise the patient to avoid end ROM positions to lessen the demand on the discs of inferior motion segments.

Keywords: Adjacent segment disease; Arthroplasty; Cervical spine; Fusion; Kinematics; Percent contributions; Range of motion; Three-dimensional

FDA device/drug status: Not applicable.

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The disclosure key can be found on the Table of Contents and at www.TheSpineJournalOnline.com.

The funding source had no influence on the data processing, the data analysis, or on the interpretation of the results, and therefore the results and conclusions of this study were not biased by the funding source.

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Introduction

It has been suggested that cervical spine segmental contributions to motion can reveal movement abnormalities associated with whiplash [1], disc herniation [2], and disc arthroplasty or fusion [3]. Segmental contributions to cervical spine flexion\extension have been estimated using end range of motion (ROM) data (typically a single full flexion and a single full extension radiograph) [3–5] and images collected from selected midrange positions [6]. Contributions to lateral bending have been determined using end range images from single-plane radiographs [2] in spite of the fact that significant out-of-plane "coupled motion" (axial rotation) occurs during the lateral bending motion [7]. A limitation of determining segmental contributions to motion using images collected at static positions is that static radiographs do not accurately represent vertebral orientation during dynamic motion [8]. Second, contributions determined using only end range positions assume (incorrectly) [9] that segmental contributions to motion are constant throughout the entire ROM. An additional limitation of previous studies is that, functionally, head motion is the most important kinematic parameter. Previous studies have neglected to determine how each cervical motion segment contributes to head motion, instead focusing on relative contributions between the C2 and C7 vertebrae [2,3,6,9]. Finally, all previous studies that reported intervertebral contributions to motion have used single-plane radiographs that do not provide sufficient information to accurately assess three-dimensional (3-D) spine kinematics during lateral bending or axial rotation.

To assess how age, injury, disease, and surgical procedures affect intervertebral contributions to head motion, a reference dataset from young, healthy individuals is necessary. Therefore, the objective of this study was to determine the cervical spine segmental contributions to head flexion\extension, lateral bending, and axial rotation during dynamic motion in young, healthy individuals.

Materials and methods

Subjects

Following Institutional Review Board (IRB) approval, and after obtaining informed consent, data were collected from 29 participants (15 men, 14 women; average age: 27.3±4.4 years; age range: 20–35). All participants were healthy asymptomatic non-smokers, with no history of neck surgery, chronic neck pain, or diagnosis of osteoporosis.

Data collection

Subjects were seated upright in a high-back chair within a biplane X-ray system and directed to continuously move their head and neck through their entire ROM for the dynamic movement trials. A metronome set at 40–44 beats per minute was used to ensure that the participants moved at a continuous, steady pace to complete each full movement cycle in approximately 3 seconds. Reflective marker data and biplane radiographs were collected for nine dynamic movement trials (flexion-extension [3], lateral bend [3], and axial rotation [3]) for each individual. An eight-camera commercial tracking system (Vicon-MX; 60 Hz; Vicon, Centennial, CO, USA) tracked reflective markers placed on the head (four) and torso (four). Radiographs were collected at 30 frames per second for 3.2 seconds for each dynamic movement trial (X-ray parameters: 70 kV, 160 mA, 2.5 ms X-ray pulses, source-to-subject distance 140 cm). Three static neutral trials were also collected while the participant looked straight ahead.

Next, high-resolution computed tomography (CT) scans (0.29×0.29×1.25 mm voxels) of the cervical spine (C1–T1) were acquired from each participant (GE Lightspeed 16; GE Medical Systems Inc., Waukesha, WI, USA). The effective radiation dose for each dynamic motion trial was estimated to be 0.16 mSv (determined using PCXMC simulation software, STUK, Helsinki, Finland). The effective dose of a cervical spine CT scan has been reported to be between 3.0 mSv and 4.36 mSv [10,11].

Data processing

Bone tissue was segmented from the CT volume using a combination of commercial software (Simpleware Software, Exeter, UK) and manual segmentation [12]. A 3-D model of each vertebra was generated from the segmented bone tissue. Markers were interactively placed on the 3-D bone models to define bone-specific anatomic coordinate systems, with the x-axis directed right to left, the y-axis directed inferior to superior, and the z-axis directed posterior to anterior [13]. In vivo bone motion was tracked using a volumetric model-based tracking technique previously described in detail [14–16]. This model-based tracking technique has been validated in vivo to have a precision of 0.33 mm or better for intervertebral translations and 1.1° or better for intervertebral rotations of the cervical spine [15]. For flexion\extension trials, all bones from C1 through T1 were tracked, whereas for lateral bend and rotation trials, only C3 through T1 were tracked, owing to the skull and mandible obscuring C1 and C2.

The bone motion obtained from model-based tracking of each vertebra was combined with head motion obtained from tracking reflective markers on the head and torso to create continuous data curves depicting motion segment angle versus head angle for each cervical motion segment. Cervical motion segment contributions to the primary head rotation were then calculated for the flexion portion of the flexion\extension movement (i.e., moving from full extension to full flexion), for the extension portion of the flexion\extension movement (i.e., moving from full flexion to full extension), and for left and right lateral bending and axial rotation. For each participant, the average segmental contributions were calculated over two trials of each movement and included in the present analysis.

This study was funded by Synthes Spine (F).

Results

During the cyclical flexion\extension motion, after the head reached full extension, the flexion movement was