

Pilot Study Quantifying Continuous Cervical Spine Axial Rotation Kinematics In-Vivo

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INTRODUCTION: Intervertebral disc (IVD) degeneration of the cervical spine is characterized by disc height loss, neck pain, and neurological symptoms. The condition occurs in 90% of people over the age of 50 and symptomatic cases often require surgical intervention, such as spinal fusion [1]. This procedure results in accelerated degeneration of adjacent discs [2], which is suspected to arise from altered kinematics [3]. Cervical total disc arthroplasty (cTDA) is an alternative intervention which may better retain native kinematics [4], however, current implant designs are primarily based on unvalidated in-vitro kinematic estimates [5]. Existing work computing kinematics during dynamic motion has been largely focused on flexion/extension, and oftentimes neglects coupled rotations occurring about the secondary axes of movement. The purpose of this study was to evaluate the feasibility of computing in-vivo cervical spine kinematics in asymptomatic control participants and produce continuous time series data for axial rotation kinematics using a previously a validated high speed biplanar video radiography (HSBV) system. Furthermore, this pilot study aimed to verify reproducibility of the data collection protocol and establish a healthy baseline for the future evaluation of dynamic cervical spine kinematics with an in-vivo cTDA surgical cohort.

METHODS: Three asymptomatic male participants (mean age: 21.0 ± 1.0 year) were recruited, under the approval by the Conjoint Health Research Ethics Board (Ethics ID: REB18-1660). Each participant gave informed consent prior to participation and was imaged using HSBV (20 Hz, 72 kVp, 160 mA) to obtain dynamic bi-planar image sequences of the C3-C6 cervical vertebrae throughout full neck axial rotation (AR) range of motion (ROM). Computed tomography scan was obtained to develop 3D bone models of the cervical vertebrae, and these models were registered to the HSBV 2D images in each frame using the DSX Suite tracking software (C-Motion). Relative 3D Cardan angles for AR, as well as flexion/extension (FE) and lateral bending (LB), were calculated for each vertebral segment throughout the primary AR movement. Continuous time series data was visualized for each participant. ROM for each rotational plane was calculated as the difference between the maximum positive rotation (counterclockwise for AR, flexion for FE, and left for LB) and the maximum negative rotation and averaged across participants. Ultimately, proximity maps of each endplate segment will be determined using a custom MATLAB (R2021b) script to estimate disc height and the weighted centroid throughout the primary movement. Cardan angles and disc height will be compared to existing results [6, 7, 8].

RESULTS SECTION: The relative C4-C5 Cardan angles were consistent across the three participants, following expected continuous motion path curves during the primary AR movement (Figure 1) when compared to literature [6]. The continuous kinematic curves in the secondary coupled rotation axes (FE and LB) exhibit more variability. ROM for the primary rotation, AR, was $11.74 \pm 0.20^\circ$. The secondary axis ROM was consistent with Wang et al. [7], averaging $7.03 \pm 1.98^\circ$ for FE and $9.82 \pm 1.41^\circ$ for LB (Table 1).

DISCUSSION: This initial analysis yielded comparable results to the literature and suggests fidelity of the data collection protocol to reproduce in-vivo cervical spine kinematics throughout axial rotation ROM. The AR ROM was greater than previously reported values; Wang et al. identified axial rotation ROM as only $6.6 \pm 1.7^\circ$ for asymptomatic controls (Table 1). However, the AR results were consistent with a standard deviation of only 0.2° despite the small sample size. This pilot study used only young male participants; this may account for the higher measured axial ROM when compared to Wang et al. (7 males, 11 females; mean age: 40.5 ± 10.9 years). Potential differences in data collection protocol and instruction may have also contributed to the greater primary movement ROM observed. Data processing has been completed for only the C4-C5 vertebral segment to date. Additional forthcoming work will compute Cardan angles for the adjacent vertebral levels (C3-C4 and C5-C6), as well as throughout primary FE and LB movements, which will be valuable to better understand the native coupled rotations for informing cTDA design and development. Furthermore, this pilot study precedes a study which will follow a similar data collection protocol and processing pipeline to evaluate the impact of a cTDA intervention on in-vivo cervical spine kinematics.

SIGNIFICANCE: This study provides evidence to suggest that HSBV can be utilized to compute healthy cervical spine kinematics during clinically relevant dynamic movements and replicate existing, though limited, datasets. Quantification of healthy in-vivo spine kinematics, including primary and coupled rotations during dynamic motions, will provide meaningful replication data on the normal movements of the cervical vertebrae, which may be used to inform the design of the next generation of cTDA prosthetics.

REFERENCES: [1] Teraguchi et al., *Osteoarthritis and Cartilage*, vol. 22, no. 1, 2014. [2] Alhashash et al., *Spine*, vol. 43, no. 9, 2014. [3] Miyazaki et al., *Spine*, vol. 33, no. 23, 2008. [4] Boselie et al., *Cochrane Database of Systematic Reviews*, vol. 9, 2012. [5] Ansari-pour et al., *J. Biomech.*, vol. 144, no.1, 2022. [6] Lin et al., *J. Biomech.*, vol. 47, no. 13, 2014. [7] Wang, et al., *J. Biomech.*, vol. 112, no. 1, 2020. [8] Anderst et al., *Spine*, vol. 14, no.7, 2016.

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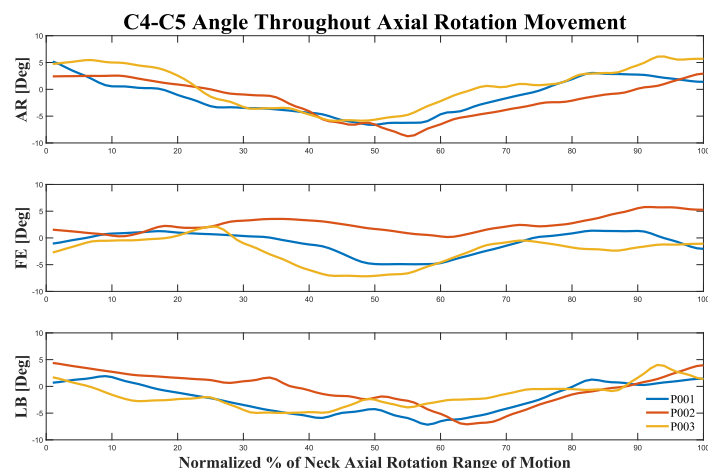


Figure 1. Axial rotation (AR), flexion/extension (FE), and lateral bend (LB) angles for C4-C5 segments during AR for each participant.

Table 1. Average rotational ROM for C4-C5 cervical segment during primary AR movement, compared with recent findings from Wang et al. [7].

	Pilot Study	Wang et al.
ROM (°)	AR	6.6 ± 1.7
	FE	5.0 ± 1.5
	LB	9.8 ± 2.8