FLEXION-EXTENSION MOTION PATHS IN THE HEALTHY CERVICAL SPINE

Maya McKeown, William Anderst, PhD, Scott Tashman, PhD
Orthopedic BioDynamics Laboratory, Synthes Spine

INTRODUCTION

For patients with cervical spinal fractures, deformities, and degenerative diseases, Synthes Spine (of Depuy Synthes), has created many medical devices for surgical insertion to decrease pain and restore cervical movement. Their devices include various fusion plates, used to fuse dysfunctional motion segments (or adjacent vertebrae and the connecting tissues that bind them) to prevent painful movement, as well as artificial disc replacements, (simulating the cushion between vertebrae) to replace dysfunctional discs and still allow for movement of the bones.

Fusion surgeries are not new to the field of cervical spinal interventions, as the first reported anterior cervical fusion (ACF) appeared in 1955[1]. Recent literature reports that ACF procedures currently account for approximately 80% of all cervical spinal procedures[2]. However, fusion procedures often lead to adjacent segment disease (ASD) in which undue stress is placed on neighboring segments of the fused spine, causing degeneration of the adjacent segments and pain[3]. To combat this, many surgeons are now turning to cervical anterior disc replacement (CADR), thought to better preserve physiological motion and biomechanics of cervical spine, and reduce the occurrence of ASD[3].

As the field of cervical spine medical devices grows more competitive, particularly for CADR, Synthes Spine wanted more information on the cervical kinematics of young, healthy subjects during three-dimensional movement to understand what healthy cervical motion is. This knowledge will allow them to create better CADRs that reproduce this normal motion, better serving patients in need of disc replacements or weary of fusions.

However, cervical spine kinematics are commonly measured clinically using static full-flexion and full-extension radiographs[4]. The most critical limitation of this type of assessment is that neither the dynamic functioning of the neuromuscular system, nor the mid-range kinematics that comprise the majority of spine motion during activities of daily living[5], can be assessed at static endpoint positions.

These limitations may be address by collecting continuous, full range of motion (ROM) intervertebral kinematics during dynamic functional loading and by calculating continuous intervertebral motion curves over the full motion path. This particular initial study assesses just the flexion-extension (F/E) movement by looking at the intervertebral F/E angle over 100% of the F/E motion cycle. Inherently, an intervertebral F/E angle assessment will be unique to each motion segment.

OBJECTIVE

The objective of this study is to generate continuous intervertebral flexion-extension curves of the cervical spine for motion segments C1-C2 through C6-C7 in young, healthy individuals during the dynamic flexion-extension movement. These continuous curves will be given to Synthes Spine, along with any pertinent observations or recommendations drawn from their analyses.

SUCCESS CRITERIA

In order to provide Synthes Spine with data regarding the kinematics of the healthy cervical spine, all materials used to reconstruct, compute, and analyze intervertebral angles throughout the overall motion path must contribute to reproducing accurate motion. In reconstructed movies of the isolated bone models moving during F/E, bone models may not shake unnaturally or collide since that is not representative of actual movement occurring in the cervical spine due to the presence of discs, nerves, and muscles. Additionally, to create such movies, bone models must be tracked in the correct location of the correct spine, so our analyses of the intervertebral angles will be accurate.

METHODS

Twenty-eight healthy young adults (27.3±4.6 yrs.; 14 M, 14 F) provided informed consent to participate in this IRB-approved study. Participants performed full ROM F/E of their head and neck to a metronome while seated within a biplane X-Ray system. Three-dimensional vertebral motion was tracked for each individual vertebrae for all 28 subjects using a volumetric model-based tracking technique that matched subject-specific bone models (obtained from CT) to the biplane radiographs collected at 30 frames/second, as shown in Figure 1. Reflective markers were placed on the head and torso to determine global head motion relative to the torso.

Figure 1: Cross registration of the 3D bone model (derived from CT) with the digitally reconstructed radiographs allows for manual and automated model based tracking of the bone in the correct orientation in 3D space.
Additionally, a software called *Create Surface* output a coordinate system for each individual vertebra depending on the location of 22 markers, manually placed at specific anatomical locations. Another software called *Kinematics* produced a movie of just the bone models moving during the overall F/E movement for analysis. Any bones colliding or shaking excessively during the motion would necessitate editing of the model based tracking for the affected bones.

*Kinematics* also calculated the intervertebral angles for each frame throughout the movie by comparing the locations of the adjacent coordinate systems for each motion segment. These intervertebral F/E angles were then normalized to the 0-100% of the head flexion and head extension range of motion. Plotting the intervertebral angles as a function of motion path percentage generated the continuous curves.

**RESULTS**
Continuous curves were plotted for each motion segment. The graphs contained the continuous curves for all 28 subjects as well as a thicker mean curve. Figure 2 is the graph of the continuous curves for the C4-C5 motion segment.

![Figure 2: C4-C5 full range of motion flexion/extension curves for 28 young healthy subjects (thin blue lines) and the group mean curve (thick blue line).](image)

The asymmetry about the middle 50% of the motion path shows that intervertebral angles are not the same in flexion as they are in extension, suggesting a dependency on the direction of the head.

Figure 3, the graph for the mean curves of each motion segment, shows that the asymmetry is not specific to the C4-C5 motion segment. Each curve has a unique shape. Additionally, the maximum flexion angle and the maximum extension angles reached were different for all motion segments.

![Figure 3: Mean continuous curves for all motion segments showing trends in asymmetry and differing ranges of flexion and ranges of extension for each motion segment.](image)

**DISCUSSION**
The asymmetry of the curves suggests that the intervertebral angles are dependent on the direction of the head, and therefore not the same during the extension movement as the flexion movement. Clinically this implies that disc replacements designed to follow asymmetric motion paths will better restore normal, healthy motion, as the asymmetry may prevent unnatural and painful compression of muscles or nerves. Additionally, this finding further affirms the need for kinematics data to be collected during dynamic full F/E movements and not just at static endpoints.

The differing ranges of maximum flexion and maximum extension along the motion path make each motion segment unique. This implies that disc replacements that allow for only a certain range of motion may be better suited for some motion segments over others. To accurately return normal motion to a patient in need, the implant should be made specific to the motion segment to allow for the correct range of motion.

All of the continuous curves, observations, and recommendations will be given to *Synthes Spine*, meeting the objective of this study. Although this initial study is limited in that it looked at only young subjects during only the F/E movement, we hope to see our suggestions acted upon in the design of disc replacements that can better restore normal motion, therefore assisting patients with cervical spinal pathologies in need of CADR.

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**REFERENCES**