The Effect of Joint Angle Calculation Method on Intervertebral Range of Motion in the Lower Cervical Spine

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Introduction: The most common methods of calculating joint angles are ordered rotations (Euler’s method) and projection angles[1]. Computational experiments have demonstrated that these different joint angle calculation methods result in differences in range of motion (ROM), and the ROM differences increase as the magnitude of rotation increases[1]. This can lead to difficulty when comparing results between studies that use different joint angle calculation methods. When selecting the order of rotations, the “rule of thumb” is to perform the ordered rotations with the largest rotation first. The proposed “standard” rotation sequence for intervertebral rotations (flexion-extension, followed by twist, and finally lateral bend)[2] does not follow this “rule of thumb” when the primary motion of the cervical spine is twisting or bending. During twist and lateral bending of the cervical spine, the magnitudes of these rotations are similar, and much larger than flexion-extension[3]. Thus, it is unclear which sequence to select for determining ROM during twisting and bending of the cervical spine, and it is not known if different methods of calculating joint angles yield significantly different results when analyzing multi-plane cervical motion. Therefore, the purpose of this study was to compare cervical intervertebral ROM as calculated by six Euler rotation sequences and two projection angle combinations. It was hypothesized that intervertebral range of motion during flexion-extension, twisting, and lateral bending of the cervical spine is not significantly different when determined by these different calculation methods.

Methods: Twenty-nine young healthy participants (27.7±4.9 years; 15M, 14F) provided informed consent to participate in this IRB-approved study. Participants performed full ROM dynamic flexion-extension, axial rotation (twist), and lateral bend movements of their head and neck within a biplane X-ray system while radiographs were collected at 30 frames per second for 3.2 seconds. A validated volumetric model-based tracking process, using subject-specific bone models (C3-C7) derived from CT, tracked bone orientation and location in 3D space for each pair of radiographs with sub-millimeter accuracy[4]. After establishing an anatomic coordinate system within each bone[5], intervertebral rotations between adjacent vertebrae were calculated during the continuous dynamic motion using 6 Euler rotation sequences (XYZ, XZY, YXZ, YZX, ZXY, ZYX)[6] and two projection angle combinations (Proj$_1$ = [$P_{xj}$, $P_{yi}$, $P_{zi}$], Proj$_2$ = [$P_{xk}$, $P_{yk}$, $P_{zj}$])[1]. Primary and coupled ROM were calculated for each movement. Repeated measures analysis of variance was used to test for within-subject differences in intervertebral ROM ($\alpha = 0.05$) as determined by each Euler rotation sequence and each projection angle combination.

Results: Statistically significant differences in intervertebral range of motion were identified among rotation sequence and projection angle combinations over all cervical motion segments (all $p<0.002$). However, the group mean ROM differences were all less than 0.95° across all motion segments and all three movements, with the 95% confidence interval of the difference less than 0.3° in all cases. In
contrast to these small differences in mean ROM for the entire group using the 8 joint angle calculation methods, ROM differences of up to 5° were identified within individual subjects (Figure 1).

These large within-subject differences in the primary rotation were observed when the magnitudes of the secondary rotation angles were large (Figure 2).

In fact, differences in the primary axis ROM between rotation calculation methods were significantly related to the magnitude of the secondary axis angles (average $R^2$ value of 0.57) (Figure 3).
Additionally, the XYZ and ZYX ordered rotations yielded results identical to the Proj$_1$ and Proj$_2$ projection angle combinations, respectively, for all movements.

**Discussion:** The hypothesis of this study was rejected, as statistically significant differences in intervertebral range of motion were determined when using different methods to calculate intervertebral ROM in the lower cervical spine. However, this study also demonstrated that, for a relatively large group, different joint angle calculation methods do not produce clinically meaningful differences in group mean intervertebral ROM during dynamic, multi-planar motion of the lower cervical spine (flexion-extension, twist, and lateral bend). Within individuals, large differences in ROM between rotation methods (up to 5°) were associated with the magnitude of the intervertebral angle in the secondary axes of rotation, not the magnitude of the ROM about the secondary axes. This is an important factor to consider when assessing ROM in symptomatic or surgical patients who may exhibit, for example, excessive lordosis at one or more motion segments of the cervical spine. The excessive lordosis (i.e. a large intervertebral flexion/extension angle at the motion segment) will magnify twist and bend ROM differences between different calculation methods. A limitation of this study is that the head-body, C1-C2, and C2-C3 motion segments were not included in the analysis, and therefore the results of this study should not be extrapolated to apply to the upper cervical spine and head motion segments.

**Significance:** ROM values can differ substantially within individual subjects when using different methods to calculate intervertebral rotation in the lower cervical spine. Therefore, the method used to calculate intervertebral ROM during multi-planar spine movement should be described in detail, and a standard method should be established in order to compare data across studies.

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