In-vivo Motion Characteristics Of The C5-C6 And C6-C7 Cervical Spine Segments During Dynamic Weight-bearing Flexion-Extension

Sean J. Driscoll, MEng, Shaobai Wang, PhD, Weiye Zhong, MD, Guoan Li, PhD, Kirkham B. Wood, MD, Thomas D. Cha, MD, MBA.
MGH, Boston, MA, USA.


Introduction: Recent in-vivo research has observed segment-dependent motion characteristics in the lumbar spine during dynamic functional activities [1]. Knowledge of segment-specific characteristics is important to better understand potential mechanical factors related to disease development (spondylolisthesis, stenosis, herniation, etc.), and the clinical outcomes following surgical intervention (spinal fusion and disc replacement). These motion characteristics may also need to be considered when determining surgical techniques and implants to best restore native spinal function. The objective of this research was to investigate the in-vivo six-degree-of-freedom (6DOF) motion characteristics of the C5-C6 and C6-C7 intervertebral levels during dynamic weight-bearing flexion-extension using a 3D dual-fluoroscopic imaging system (DFIS).

Methods: 8 asymptomatic subjects (4 males, 4 females, average age: 39.1±9.4 years, average BMI 24.3±3.6 kg/m2) were recruited to investigate the 6DOF dynamic range of motion (DROM) during weight-bearing cervical flexion-extension. The cervical spine was imaged using the DFIS as subjects moved dynamically through their full flexion-extension range of motion. The speed of the motion was paced by the beats of a metronome set at 40 beats per minute, such that one full cycle of the movement took approximately 3 seconds [2, 3]. A static image of each subject in their neutral weight-bearing position was also collected. 3D vertebral models of the C5-C7 vertebrae were constructed for all subjects from MRI scans. The models and fluoroscopic images were then used to reproduce the vertebral positions along the dynamic motion path of one full flexion-extension cycle. Intervertebral kinematics in 6DOF were calculated from local coordinate systems, established in the center of the vertebral bodies, as the motion of the superior vertebrae relative to its adjacent inferior vertebrae (Figure 1). The dynamic intervertebral kinematics were determined relative to the kinematics of the static neutral posture. DROM was calculated from the maximum and minimum values of each DOF throughout the cycle. Student’s t-tests were used to analyze the 6DOF DROM differences between the C5-C6 and C6-C7 levels.

Results: Table 1 displays the mean 6DOF DROM and p-value results when comparing the C5-C6 and C6-C7 levels. The results show C5-C6 has significantly more anterior-posterior (AP) translation (4.22 mm) and flexion-extension (FE) rotation (15.8°) than C6-C7 (2.89 mm and 10.0°, respectively). Motions in other DOFs were similar and relatively small (Table 1, Figure 2).

Discussion: Intervertebral level-specific motion characteristics of asymptomatic subjects were examined during dynamic weight-bearing cervical flexion-extension. C5-C6 showed significantly more AP
translation and FE rotation than C6-C7. Given the similarity in maximum flexion intervertebral angles between levels, the increase in FE DROM at C5-C6 is the result of increased maximum extension (Figure 2). The data could provide baseline information for the segment-specific motion characteristics required to restore native spine function, at both the diseased and adjacent levels, following surgical intervention. The data may also provide important insights for investigation of segment-dependent cervical pathology. Future work will examine the motion characteristics of patients with cervical disc degeneration to further understand potential mechanical factors of disease development.

**Significance:** Level-specific intervertebral motion characteristics were observed between C5-C6 and C6-C7. Clinical evaluation and treatment of the lower cervical spine may need to be segment-dependent.

Figure 1: Intervertebral kinematics in 6DOF were calculated: flexion-extension rotation (FE), lateral side-bending rotation (SB), axial twisting rotation (Twist), medial-lateral translation (ML), anterior-posterior translation (AP), and superior-inferior translation (SI).

<table>
<thead>
<tr>
<th>6DOF DROM</th>
<th>ML (mm)</th>
<th>AP (mm)</th>
<th>SI (mm)</th>
<th>FE (°)</th>
<th>SB (°)</th>
<th>Twist (°)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C5-C6</td>
<td>1.50 (0.62)</td>
<td>4.22 (1.58)</td>
<td>1.68 (0.48)</td>
<td>15.8 (4.8)</td>
<td>1.9 (0.8)</td>
<td>1.3 (0.4)</td>
</tr>
<tr>
<td>C6-C7</td>
<td>1.36 (0.78)</td>
<td>2.89 (0.88)</td>
<td>1.95 (0.69)</td>
<td>10.0 (4.4)</td>
<td>2.1 (1.4)</td>
<td>1.6 (0.9)</td>
</tr>
<tr>
<td>p-value</td>
<td>0.676</td>
<td>0.020</td>
<td>0.191</td>
<td>0.000</td>
<td>0.567</td>
<td>0.189</td>
</tr>
</tbody>
</table>

Table 1: 6DOF DROM is expressed as mean (standard deviation). 6DOF DROM p-values indicate Student’s t-test results between the C5-C6 and C6-C7 levels. Shaded cells indicate statistically significant results (p < 0.05).
Figure 2: Dynamic 6DOF motion characteristics during one complete flexion-extension cycle (i.e. full extension to full flexion to full extension).