DEVELOPMENT OF A COMPUTERIZED INTERVERTEBRAL MOTION ANALYSIS OF THE CERVICAL SPINE FOR CLINICAL APPLICATION

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ABSTRACT

Objective: The objective of this study was to develop a measurement method that could be implemented in chiropractic for the evaluation of angular and translational intervertebral motion of the cervical spine.

Methods: Flexion-extension radiographs were digitized with a scanner at a ratio of 1:1 and imported into a software, allowing segmental motion measurements. The measurements were obtained by selecting the most anteroinferior point and the most posteroinferior point of a vertebral body (anterior and posterior arch, respectively, for C1), with the origin of the reference frame set at the most posteroinferior point of the vertebral body below. The same procedure was performed for both the flexion and extension radiographs, and the coordinates of the 2 points were used to calculate the angular movement and the translation between the 2 vertebrae.

Results: This method provides a measure of intervertebral angular and translational movement. It uses a different reference frame for each joint instead of the same reference frame for all joints and thus provides a measure of motion in the plane of each articulation. The calculated values obtained are comparable to other studies on intervertebral motion and support further development to validate the method.

Conclusion: The present study proposes a computerized procedure to evaluate intervertebral motion of the cervical spine. This procedure needs to be validated with a reliability study but could provide a valuable tool for doctors of chiropractic and further spinal research. (J Manipulative Physiol Ther 2007;30:38-43)

Key Indexing Terms: Range of Motion; Articular; Neck; Spine; Radiography

The evaluation of intervertebral motion is essential for chiropractors and other spinal manipulation therapists. In daily practice, motion palpation is

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the main tool used to evaluate spinal joint movement and restriction. Although there have been efforts to develop a standardized motion palpation technique,1 results of studies looking at the sensitivity of range of motion tests and pain have varied greatly. Poor sensitivity was reported for range of motion studies,2 and interexaminer and intraexaminer reliability greatly needs improvement.3 Because the spinal palpatory tests play a determinant role in the treatment plan, a reliable palpation method or an objective tool that is not dependent on individual perceptions is necessary. Moreover, when flexion-extension radiographs are indicated in a clinical context, no standardized method is available to accurately analyze the intervertebral motion. Various objective methods already exist to evaluate segmental motion of the spine.4 Among them, magnetic resonance imaging,5 ultrasound, and inclinometry6 have been proposed. However, chiropractors need a precise but practical tool that can be implemented in daily practice.

Numerous studies have proposed different methods of evaluating segmental motion through analysis of sagittal plane radiographs.7-10 However, the current methods are either not precise enough or are unavailable for application within the context of chiropractic care. The method of
Henderson and Dormon is quite practical, although it does not have the precision of a computerized analysis in calculating the geometry of the movement. Among the computerized methods, Frobin et al proposed a very precise type of analysis, but it is not expected to be available and accessible to chiropractors. Therefore, the aim of this study was to develop a measurement tool that could be put into practice by chiropractors for the evaluation of intervertebral motion of the cervical spine. This tool allows calculation of the angular movement and the translation of one vertebra on the one below it. The present software analysis might be less accurate than other methods found in the literature but still has a great potential for precision. In this feasibility study, we wished to evaluate the ability of our method to measure the angular and translational intervertebral movement with the existing software. In a future study, we would like to evaluate the reliability of the method in a clinical setup with our own software. We hypothesized that the analysis would provide similar measurements to those obtained with other accurate analysis. The interest of the present method is that it combines precision (computerized analysis) and simplicity (the user only needs to select points on the radiographs), which is a great advantage for clinical use. Here, we describe the procedure we used to analyze intervertebral motion, and we report the measurements obtained from 30 patients.

**METHODS**

**Subjects and Sagittal Plane Radiographs**

Flexion-extension radiographs of 30 patients (24 women, with ages 17-40 years, mean age of 30 years; 6 men, with ages 20-51 years, mean age of 41 years) were collected from the database of the chiropractic clinic of the University of Trois-Rivières for this retrospective study. Patient files from 1993 to 2004 were randomly selected from the database if they included flexion-extension radiographs. All files included had a clinical indication for radiographic examination to rule out various diseases, but none had a pathological condition. Radiographs were included if they could clearly show at least the first 6 cervical vertebrae and were excluded if there was any pathology that could importantly affect motion as degenerative joint disease, all

**Fig 1. Detailed calculations for the translational and angular movement measurements obtained from the coordinates of the points selected on the radiographs.**

**Flexion:** coordinates of arrow 2 (x1,y1) and 3 (x2,y2) (for C1-C2) and 5 (x3,y3) and 6 (x4,y4) (from C2-C3 to C6-C7)

**Extension:** coordinates of arrow 2’ (x1’,y1’) and 3’ (x2’,y2’) (for C1-C2) and 5’ (x3’,y3’) and 6’ (x4’,y4’) (from C2-C3 to C6-C7)

**Calculation of the translational movement**

Using the coordinates of arrows 2 and 2’ (C1-C2) or arrows 5 and 5’ (from C2-C3 to C6-C7)

For C1-C2: 
\[
\begin{align*}
\text{x movement} &= x_1 - x_{1'} = \Delta x \\
\text{y movement} &= y_1 - y_{1'} = \Delta y
\end{align*}
\]

For C2-C3 to C6-C7: 
\[
\begin{align*}
\text{x movement} &= x_3 - x_{3'} = \Delta x \\
\text{y movement} &= y_3 - y_{3'} = \Delta y
\end{align*}
\]

**Intervertebral translational movement = Square root of (\Delta x^2 + \Delta y^2)**

**Calculation of the angular movement**

Using the coordinates of arrows 2-3 and 2’-3’ (C1-C2) and arrows 5-6 and 5’-6’ (from C2-C3 to C6-C7)

For C1-C2: 
1- slope between 2 and 3 = \(x_1 - x_2, y_1 - y_2 = \Delta x / \Delta y\) 
2- slope between 2’ and 3’ = \(x_1' - x_2', y_1' - y_2' = \Delta x' / \Delta y'\) 
3- Arctan(\(\Delta x / \Delta y\)) – Arctan(\(\Delta x' / \Delta y'\)) = intervertebral angular movement

For C2-C3 to C6-C7: 
1- slope of line C: \(x_3 - x_4, y_3 - y_4 = \Delta x / \Delta y\) 
2- slope of line C’: \(x_3' - x_4', y_3' - y_4' = \Delta x' / \Delta y'\) 
3- Arctan(\(\Delta x / \Delta y\)) – Arctan(\(\Delta x' / \Delta y'\)) = intervertebral angular movement
types of arthritis, or congenital conditions such as block vertebra. A retrospective study was preferred to avoid unnecessary exposure of healthy volunteers to radiation. The use of these data was approved by the Trois-Rivières University human research ethical committee.

**Procedure for Segmental Motion Analysis**

All procedures were made by 2 certified chiropractors and a board certified chiropractic radiologist or by trained chiropractic students under their supervision. The measurements obtained by the chiropractic students were verified by the 2 certified chiropractors. The radiographs were digitized with an HP Scanjet 2CX scanner (Hewlett Packard, Palo Alto, Calif, USA) at a ratio of 1:1 and then imported into AutoCAD 2002 (Autodesk Inc, San Rafael, Calif, USA) for segmental motion measurements. Potential artifacts such as image size distortion, loss of contrast, or brightness were examined. No artifact or distortion was produced, and no manipulation of images such as contrast and brightness enhancement was necessary.

The measurements were obtained by selecting, with the computer mouse, the most anteroinferior point and the most posteroinferior point of a vertebral body (anterior and posterior arch, respectively, for C1) with the origin (0,0) of the reference frame set at the most posteroinferior point of the vertebral body below. For example, for C2 measurements, the origin was set at the most posteroinferior point of C3 vertebral body, and the 2 other points were set on C2 as described above. The precision of the selection was increased by zooming in on the area of interest. When setting the 2 points of a vertebral body, the coordinates of the 2 points were noted for calculation. The calculation was done in Microsoft Excel (Microsoft, Inc, Redmond, Wash, USA) as described in Fig 1. The same procedure was performed for both the flexion and extension radiographs, and the coordinates were then used to calculate the angular movement and the translation between the 2 vertebrae. For each joint, the origin of the reference frame was set by selecting the most posteroinferior point of the inferior plate of the inferior vertebra. For example, for C5-C6, the origin of the reference frame became the most posteroinferior point of the inferior plate of C6. This method allowed calculation of the movement between 2 vertebrae instead of the movement of 1 vertebra in a static 2-dimensional reference frame (where the origin is not set for each joint but is rather the same for all).

An illustration of the procedure is shown in Figs 2 and 3. The flexion radiograph is analyzed first (Fig 2). For C1-C2, a line is drawn along the inferior plate of the body of C2 (line A). Then, the origin (0,0) for C1 measurements is set on the most posterior point of the inferior plate of C2 (arrow 1), and the x-axis is set along line A. Then, the \((x',y')\) coordinates of the anterior arch of C1 (arrow 2) and the most posterior point of the posterior arch of C1 (arrow 3) are determined. This procedure is repeated for the extension radiograph (Fig 3), and the \((x',y')\) coordinates are obtained by drawing line \(A'\), setting the origin (arrow \(1'\)), and determining the most anterior point of the anterior arch of C1 (arrow \(2'\)) and the most posterior point of the posterior arch of C1 (arrow \(3'\)).
To get the translation between C1 and C2 during active maximum flexion and active maximum extension along the axis of line A/A’, the values of the arrow 2’ coordinates (extension) are subtracted from the values of arrow 2 coordinates (flexion). Then, the total displacement (the vector of Δx and Δy) is obtained by using the Pythagorean theorem to calculate the square root of (Δx^2 + Δy^2).

To calculate the angular movement between active maximum flexion and active maximum extension between C1 and C2 (Fig 1), the Arctan of the slope between arrows 2 and 3 (flexion) is subtracted from the Arctan of the slope of line C (extension), which is also shown in Fig 1. The resulting value represents the intervertebral angular movement between C4 and C5.

### Statistical Analysis

The values of angular and translational movement of each joint were tested for normality (Shapiro-Wilk test). This basic statistical analysis was performed to validate the sample data taken from the 30 patients but is not intended to establish any standard of intervertebral motion. The null hypothesis is that the sample is taken from a normal distribution. The supposition of normality is then rejected for P < 0.05.

### RESULTS

The angular and translational movements were calculated from C1-C2 to C6-C7 and are presented in Tables 1 and 2, respectively. The Shapiro-Wilk test indicates that the samples for most measurements were normally distributed. One major exception is the translational movement for C6-C7, which shows great variability with an SD of 6.0 mm, for an average movement of 5.8 mm. However, it is to be noted that for that segment, only 15 of the 30 sets of radiographs allowed the analysis; the remaining did not show the vertebrae well enough for the measurements to be taken appropriately. At this point of the method development, no conclusion should be made concerning the mobility of each joint in the sample.

### DISCUSSION

A comparison of different studies measuring the angular intervertebral movement is made in Table 3. The results obtained in the present study are comparable with the previous literature, although there is some variability across studies. The results most similar to the present study are the angular measurements from Frobin et al. This is a

### Table 1. Statistical analysis of the intervertebral angular movement from C1-C2 to C6-C7

<table>
<thead>
<tr>
<th>Joint</th>
<th>n</th>
<th>Mean (degrees)</th>
<th>SD</th>
<th>SE</th>
<th>Shapiro-Wilk</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1-C2</td>
<td>30</td>
<td>11.6</td>
<td>5.3</td>
<td>0.96</td>
<td>0.9608</td>
<td>.3246</td>
</tr>
<tr>
<td>C2-C3</td>
<td>30</td>
<td>10.5</td>
<td>4.7</td>
<td>0.85</td>
<td>0.9532</td>
<td>.2052</td>
</tr>
<tr>
<td>C3-C4</td>
<td>30</td>
<td>15.6</td>
<td>5.7</td>
<td>1.03</td>
<td>0.9512</td>
<td>.1817</td>
</tr>
<tr>
<td>C4-C5</td>
<td>30</td>
<td>16.1</td>
<td>6.2</td>
<td>1.14</td>
<td>0.9705</td>
<td>.5534</td>
</tr>
<tr>
<td>C5-C6</td>
<td>30</td>
<td>15.0</td>
<td>7.3</td>
<td>1.34</td>
<td>0.9436</td>
<td>.1135</td>
</tr>
<tr>
<td>C6-C7</td>
<td>15</td>
<td>14.1</td>
<td>4.4</td>
<td>1.14</td>
<td>0.9723</td>
<td>.8999</td>
</tr>
</tbody>
</table>

The number of measures (n) is indicated with the mean value, SD, and SE. The results for the Shapiro-Wilk test are also presented. All samples are likely to be from a normal distribution.

### Table 2. Statistical analysis of intervertebral translational movement from C1-C2 to C6-C7

<table>
<thead>
<tr>
<th>Joint</th>
<th>n</th>
<th>Mean (mm)</th>
<th>SD</th>
<th>SE</th>
<th>Shapiro-Wilk</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1-C2</td>
<td>30</td>
<td>4.6</td>
<td>1.8</td>
<td>0.33</td>
<td>0.9729</td>
<td>.6206</td>
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<tr>
<td>C2-C3</td>
<td>30</td>
<td>3.5</td>
<td>1.3</td>
<td>0.23</td>
<td>0.9108</td>
<td>&lt;.05</td>
</tr>
<tr>
<td>C3-C4</td>
<td>30</td>
<td>4.7</td>
<td>1.8</td>
<td>0.32</td>
<td>0.8153</td>
<td>&lt;.05</td>
</tr>
<tr>
<td>C4-C5</td>
<td>30</td>
<td>4.2</td>
<td>1.2</td>
<td>0.22</td>
<td>0.9769</td>
<td>.7394</td>
</tr>
<tr>
<td>C5-C6</td>
<td>30</td>
<td>3.7</td>
<td>1.3</td>
<td>0.24</td>
<td>0.9681</td>
<td>.4882</td>
</tr>
<tr>
<td>C6-C7</td>
<td>15</td>
<td>5.8</td>
<td>6.0</td>
<td>1.55</td>
<td>0.5804</td>
<td>&lt;.05</td>
</tr>
</tbody>
</table>

The number of measures (n) is indicated with the mean value, SD, and SE. The results for the Shapiro-Wilk test are also presented. Note the nonnormality (P < 0.05) of the samples for C2-C3, C3-C4, and C6-C7.
particularly interesting finding because their method was very precise and used a large sample (n = 137).

In this study, we report a computerized method to evaluate translational and angular movement of the cervical spine. The results obtained from 30 sets of flexion and extension radiographs indicate that this method gives measurements comparable to those described in other studies in the literature (Table 3). This finding supports further developments of the present method to make it accessible for clinical applications. But first, it will need to be validated. This will be done by an interexaminer and intraexaminer reliability study using our own software program, which is designed to take all of the measurements necessary for the procedure described here and which is currently under development. In addition, a pilot study with chiropractors in their practice is mandatory. Second, the normal and pathological movement needs to be characterized with a large sample of healthy subjects and patients.

Previous studies using sagittal plane radiographs have reported angular movement for flexion and extension separately. Although we could have used the neutral radiographs to do this, we believed that it would introduce a significant source of variability because the neutral position is quite difficult to standardize for all subjects. Therefore, we decided to calculate the total angular and translational movement instead. Although it provides less information about the direction in which joint movement is restricted or augmented, it is a fair compromise for lesser variability and greater reliability across subjects. To address the problem of certain measurements in this study that presented great variability, namely those of C6-C7 translational movement, we will increase the sample size in a future prospective study. To ensure that more sets of radiographs will show C7 appropriately, sandbags held by the patient will be used to allow better visualization of the cervicothoracic area. The limitation concerning the low number of subjects is further emphasized by the non-normality (P < .05) of the samples for C2-C3, C3-C4, and C6-C7, as indicated by the Shapiro-Wilk test (Table 2). Future studies should include a greater number of subjects to ascertain that all samples are from a normal distribution.

Although the present procedure is computerized, it does not have the precision of the method described by Frobin et al. However, it would be very simple for chiropractors to execute once integrated in a calculating software program. Moreover, although point selection with a computer mouse involves a certain error, special care is taken to increase the precision of each selection by zooming in on the region of interest. Taking the anteroinferior point from the intersection of the line of the inferior plate of the vertebral body and its orthogonal (from C2-C3 to C6-C7) also helps for the reliability of the method that will be tested in a future study.

The most important limitation of this study is the lack of control for sources of variability in the measurements. For instance, because the study is retrospective, there was no control for the positioning of the patients and for the maximum flexion and extension instructions. In addition, this method cannot control for the distortion brought by rotation for lateral flexion. In a future prospective study, those factors will need to be controlled for. Further limitation is the lack of examiner standardization, as the results were obtained by different examiners. However, with a reliability study, the variability introduced by this factor will be controlled for.

An important issue concerning the selection of subjects in this study is radiation exposure. Because this is a retrospective study, we avoided x-ray exposure to healthy volunteers without clinical indication because it is not ethically acceptable at this point. However, this has to be taken into account in the interpretation of the results that do not provide any standard for normal motion at this point. It is also important to stress that this method is not intended to be used as a systematic examination procedure. It could be useful when flexion-extension radiographs are clinically indicated, but the aim of this method is also to provide a way to get objective measurements to help the development of noninvasive procedures, such as standardized motion palpation. For example, it would be interesting to compare the results of palpatory tests evaluating intervertebral motion with the measurements obtained with the validated software. Such a comparison could help to develop a more

<p>| Table 3. Comparison of the results for angular movement calculated in the current study with results from previous studies by different authors |</p>
<table>
<thead>
<tr>
<th>---------------------------------------------</th>
<th>----------------</th>
<th>----------------</th>
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<th>----------------</th>
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</tr>
</thead>
<tbody>
<tr>
<td>C1-C2</td>
<td>11.6</td>
<td>19</td>
<td>15</td>
<td>10.9</td>
<td>11.6</td>
</tr>
<tr>
<td>C2-C3</td>
<td>10.5</td>
<td>17</td>
<td>12</td>
<td>8.4</td>
<td>7.8</td>
</tr>
<tr>
<td>C3-C4</td>
<td>15.6</td>
<td>24</td>
<td>17</td>
<td>15.2</td>
<td>11.6</td>
</tr>
<tr>
<td>C4-C5</td>
<td>16.1</td>
<td>18</td>
<td>21</td>
<td>17</td>
<td>14.4</td>
</tr>
<tr>
<td>C5-C6</td>
<td>15.0</td>
<td>18</td>
<td>23</td>
<td>17.9</td>
<td>12.2</td>
</tr>
<tr>
<td>C6-C7</td>
<td>14.1</td>
<td>21</td>
<td>21</td>
<td>11.4</td>
<td>9.8</td>
</tr>
</tbody>
</table>

Measurements are in degrees.
reliable noninvasive technique for the evaluation of the segmental range of motion of the cervical spine.

Although this procedure involves digitization of plain films or the use of digital radiology that could be an obstacle for some practitioners, it could become a valuable diagnostic tool for the evaluation of intervertebral motion. It is also worthwhile to mention that a growing number of practitioners use digital x-ray equipment, which facilitates the application of our method.

CONCLUSION

The present study provides a computerized procedure for the evaluation of intervertebral motion of the cervical spine. After further developments, this method could lead to a valuable tool for diagnostic and research purposes.

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