Age and Gender Related Normal Motion of the Cervical Spine

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The purpose of this study was to develop a clinical method for measuring three-dimensional motion of the cervical spine using the CA 6000 Spine Motion Analyzer (Orthopaedic Systems Inc., Hayward CA). Normal values for passive examinations of flexion-extension, lateral bending, rotation, rotation out of maximum flexion, and rotation out of maximum extension were obtained and analyzed for each gender in a group of 150 normal subjects. Gender classifications were further subdivided into age groups, with each decade containing asymptomatic volunteers. Values for each group were compared for differences with respect to age and gender differences. A detailed error analysis was also performed on the interobserver and intraobserver repeatability, differences between passive and active testing, and the use of different fixation devices. Significantly decreased motion differences were found between age groups within gender, and between gender groups in corresponding decades. Results of rotation out of maximum flexion suggest support earlier conclusions that the rotation of the C1-C2 segment does not decrease with age, but rather increases slightly to perhaps compensate for the overall decreased motion in the lower segments. [Key words: cervical spine, kinematics, three-dimensional motion, normal population.]

The measurement of motion in the cervical spine is a routine part of the clinical examination of patients suffering from neck pain. Various methods for recording data, with varying degrees of accuracy and repeatability, are used in this respect, ranging from functional radiographs, to the use of different types of goniometers, to visual estimation of motion.5,9,17 There remains a need for a standard noninvasive, accurate, and repeatable clinical method by which to measure motion of the cervical spine in three dimensions.

Knowledge of normal motion patterns and ranges of motion is important in acquiring an understanding of not only normal movement, but for use as a diagnostic aid in patients with neck pain. There have been many studies on cervical spine motion, however, most have focused on sagittal plane motion.5,8,9,14 Several studies to measure other motions in the cervical spine have also been undertaken. Panjabi et al15 used stereophotogrammetry in an in vitro study to measure three-dimensional motion of the upper cervical spine, whereas Mimura et al12 used similar bi-planar roentgenographic analysis to measure in vivo axial rotations. Dvorak et al and Penning used functional computed tomographic scans to measure rotation in the cervical spine.6,7,15 Recently, three-dimensional electrogoniometric studies have been performed by Alund et al1 and Berger,9 however, the first study results were based on only ten normal persons using only active tests, and the second focused on motion patterns of various patients.

The purpose of this study was to establish a reliable, noninvasive, clinical method for measuring in vivo cervical spine motions in three planes, to accumulate a database of normal values and determine if differences exist in normal subjects as related to age and sex.

■ Methods

Examined Population. To obtain normal values, 150 healthy, asymptomatic volunteers were tested. The volunteers were broken down into groups based on sex and the following age decades: 20–29, 30–39, 40–49, 50–59, and older than 60 years (Table 1).

Measurement Equipment. The three-dimensional motion measuring device used in the study was the CA 6000 Spine Motion Analyzer (Orthopaedic Systems Inc., Hayward CA). The CA 6000 spine analyzer consists of a linkage device with high precision potentiometers connected by a series of seven bars (Fig. 1). The six potentiometers allow unrestricted three-dimensional motion to occur, and a computer software program running on a personal computer records and converts in real time the changes in the resistance of each pot due to motion into a corresponding change in angle from an initial zeroed (rest) position. There are three potentiometers to measure flexion-extension, two potentiometers to measure lateral bending, and one pot to measure axial rotation. The program computes both the main motion and the two remaining coupled motions in degrees versus time (Figure 2).

Technique for Examinations. The examination is carried out by connecting the CA 6000 Spine Motion Analyzer to the
Table 5. Average Range of Motion Values and Standard Deviations for All Passive Tests

<table>
<thead>
<tr>
<th>Age Decade</th>
<th>Flexion Extension</th>
<th>Lateral Bending</th>
<th>Axial Rotation from Flexion</th>
<th>Rotation from Extension</th>
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<tr>
<td>Male</td>
<td>Female</td>
<td>Male</td>
<td>Female</td>
<td>Male</td>
</tr>
<tr>
<td>20-29</td>
<td>132.7 (22.3)</td>
<td>149.3 (11.7)</td>
<td>101.1 (13.3)</td>
<td>106.0 (8.6)</td>
</tr>
<tr>
<td>30-39</td>
<td>141.1 (14.0)</td>
<td>158.9 (22.3)</td>
<td>104.1 (10.0)</td>
<td>108.3 (8.0)</td>
</tr>
<tr>
<td>40-49</td>
<td>131.1 (15.5)</td>
<td>139.8 (12.0)</td>
<td>92.7 (9.3)</td>
<td>96.2 (16.1)</td>
</tr>
<tr>
<td>50-59</td>
<td>136.2 (15.1)</td>
<td>152.8 (14.1)</td>
<td>88.3 (10.1)</td>
<td>91.8 (10.2)</td>
</tr>
<tr>
<td>Overall</td>
<td>116.3 (13.7)</td>
<td>133.2 (17.6)</td>
<td>74.2 (14.3)</td>
<td>75.8 (18.0)</td>
</tr>
</tbody>
</table>

*Significant difference from cell directly adjacent below (i.e., age group within gender differences).
Significant difference from cell directly adjacent to the right (i.e., gender within age group differences).

In terms of the examination procedure, we have found the established examination routine to be simple, easy to implement, and quite feasible in a clinical setting. The implementation of a fixation chair is important in that the chair reduces the involvement of the thoracic spine and provided a better method with which to isolate cervical motion. In preliminary examinations conducted with the company's rubber strap fixation, visual recognition of slippage and inconsistency were confirmed by unreliable data, and thus further proved the necessity for a fixation chair.

Interindividual and intraindividual reproducibility results are encouraging. Relatively high correlation between observers indicates that the testing routine is applicable for different examiners. The small differences we found might indicate that the experience level of the examiner may have an effect on the results of the range of motion, especially in performing the more complicated combined motions (e.g., rotation out of flexion), however these differences were not part of the current study (Table 4). Intraobserver reliability during the 3-day period is very good. An average coefficient of variation of 4.0 supports this observation. The unitless comparison factor is comparable for all tests and again the value of 4.0 indicates a very good repeatability as reported by Simpson et al.19

In each examination, the examiner performed each motion three times. A critical review of the literature finds that the American Medical Association (Guides to the Evaluation of Permanent Impairment) allows for a variation of ± 10% or 3° of the total motion, whichever is larger, among the tests, and that values not falling within this range are not valid. In our tests with the same examiner, the variation within the same test was invariably lower than the AMA guidelines allow. The effectiveness and overall value of these guidelines are the focus of an ongoing study.

Passive Versus Active Examinations

The subject of the study was to determine the total range of motion in the normal cervical spine. Based on our direct comparison of the different methods of testing, as well as the previously established results for functional roentgenographs,8,9 it is well established that a passive examination results in a larger motion. In this respect, we also observed significantly larger ranges of motion with the passive tests, all with smaller standard deviations. The one exception to this is the range of motion of rotation out of maximum flexion. The reason for this being that in the active tests, despite instructions warning against it, volunteers were free to move out of maximum flexion during the rotation. This presumably unblocks the lower segments and allows rotation to occur in the lower segments. Therefore, if the aim of an examination is to determine the range of possible motion, we strongly advocate the passively performed examination, while acknowledging that the active test might be of use in analysis of coupled motion patterns, which is not the subject of the current study.

Motion Observations

In comparing gender groups, significant differences were found between sexes within the same decade. In the age decade 20-29, there were no significant differences, however for the 30-39 age decade, significant differences were found for all motions except rotation out of maximum extension. It is interesting to note that women showed the greater range of motion in all these motions. In the 40-49 decade, women again showed a significantly larger range of motion in axial rotation and rotation out of maximum flexion. In the 50-59 age decade, men showed significantly larger differences in lateral bending and rotation out of maximum extension. There were no significant differences between gender groups for the older than 60 age group.

The well established clinical observation that motion of the cervical spine decreases with age because of the development of degenerative changes,10 has been confirmed in our study (Figure 4). An exception to this finding was the surprising observation that the rotation of the upper cervical spine, mainly at the atlantoaxial joint (tested by rotating the head in maximum flexion of the cervical spine), does not decrease with age. The measurement data for rotation out of maximum flexion suggest that the rotation of the atlantoaxial joint does not decrease with age, but rather remains constant or in fact increases slightly to perhaps compensate for the reduced motion in the lower segments.

A direct comparison of the range of motion of the cervical spine to other studies was limited by the fact that
Table 3. Intraobserver Repeatability Study

<table>
<thead>
<tr>
<th>Test</th>
<th>Day 1</th>
<th>Day 2</th>
<th>Day 3</th>
<th>Coefficient of Variation</th>
<th>Test</th>
<th>Day 1</th>
<th>Day 2</th>
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<th>Coefficient of Variation</th>
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Average of 12:

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</table>

Increased. Average values for age decades for each motion as well as averages for the gender groups along with significant differences are given in Table 5.

Discussion

Measurement Error

The technical considerations in this type of examination are straightforward and quite sound. The equipment itself has been reported by the company to be quite accurate and reliable, and our independent investigations have confirmed these claims.

Table 4. Interobserver Repeatability Study

<table>
<thead>
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<th>% Diff.</th>
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<td>Average</td>
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</table>

Passive examinations were conducted on ten random patients by two examiners, one after the other. Correlation coefficients were calculated to indicate how reproducible results were with different examiners on the same volunteer.

Figure 4. Graph indicating an overall decrease in motion as age increases. Average values for all five motions studied are plotted for each age decade average. Notice the large jump between the 30–39 to 40–49 age groups for all motions, as well as the fact that rotation out of flexion remains constant for all age groups.
other studies do not offer age- and sex-related normal values based on passive examinations for a sufficient number of normal subjects.1,2,12,13 As a general observation, however, results from our study show higher overall ranges of motion and similar standard deviations, again strengthening the observation that to obtain the total possible range of motion, passive testing provides a more suitable option.

Based on the experience of the examined population, the clinical application for the assessment of range of motion using the CA 6000 could be performed in the following patient groups:

- after soft tissue injuries of spine;
- to investigate the influence of different therapeutic methods, including manual therapy;
- to evaluate the influence of cervical spine surgery (fusions), as a function of time (compensatory mechanisms);
- to evaluate the influence of temporary segmental fixation on the total range of motion for temporary external fixation of the cervical spine;11
- for the evaluation of permanent impairment.

## Conclusions

The in vivo assessment of cervical spine motion by using the CA 6000 Spine Motion Analyzer is a reliable, reproducible method of clinical examination of the range of motion. Currently these examinations can be satisfactorily performed: flexion-extension, lateral bending, axial rotation, rotation out of maximum flexion (atlantoaxial rotation), and rotation out of maximum extension.

Age- and sex-related normative values were established and showed significant differences both between genders and age decades. These findings suggest that comparison methods currently in use are subject to error and invalid, and that age- and sex-related differences must be considered in all examinations of ranges of motion of the cervical spine.

## References


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Motion Characteristics of the Lumbar Spine in the Normal Population

Alison H. McGregor, MSc, MCSP, Ian D. McCarthy, PhD,
and Sean P. Hughes, MS, FRCS

Study Design. The present study investigated the
dynamic motion characteristics of the lumbar spine in
the normal population using a potentiometric analysis
system.

Objectives. To assess the ability of a triaxial poten-
tiometric analysis system to measure dynamic motion
in the lumbar spine, and to use this system to form a
database of dynamic motion characteristics from which
normal parameters of motion and the factors affecting
this motion could be defined.

Summary of Background Data. Spinal motion has
been studied using a variety of different methods. The
majority of which have been limited either in terms of
reliability, accuracy, or invasiveness and many have
been only of a static nature. There has been no previ-
ous study into the normal dynamic motion characteristics
of the lumbar spine.

Methods. The accuracy of the system was deter-
mined by a series of tests against a calibrated engi-
neering mill, and the reliability of the system was as-
essed on 10 subjects with repeated measurements
over a 3-day period. Values of range of motion and an-
gular velocity were obtained from 232 normal subjects
during flexion and extension, lateral flexion, and rota-
tion.

Results. The results of the calibration testing re-
vealed excellent accuracy, and it was shown that the
system was repeatable. Initial analysis of the results in-
dicated that sex differences did exist with men having
58.4° of flexion and women having 53.4°. Age appeared
to have an influence on motion, and a gradual reduc-
tion was seen with each decade (P < 0.001), with the
20–29-year age range having 59.8° mean flexion, the
30–39-year group having 58.1°, the 40–49-year group
having 53.7°, the 50–60-year group having 57.6°, and
the 60–70-year group having 45.9°. Multiple regres-
sion analysis revealed that only a few factors are impor-
tant with respect to motion and that these varied ac-
cording to the characteristics being defined.

Conclusions. Range of motion tended to be affected
by age and sex, whereas velocity was only affected by
distance moved, with occupation and body mass index
having little or no influence on motion. The factors
identified could only account for a small proportion
of the variation seen, suggesting that it is difficult to pre-
dict the motion characteristics with any degree of sen-

Spinal pain is the most common complaint of patients
presenting with musculoskeletal disorders,8 and the Na-
tional Back Pain Association9 stated that 80% of the
population will suffer at least one disabling bout of low
back pain (LBP) during their lives. Traditionally, the
management of LBP is based on the clinical history
and physical findings, with emphasis being placed on
the measurement of physical function because it is more
objective and quantifiable than subjective pain.9,10 It
is believed that abnormal spinal mechanics are associ-
ated with abnormal spinal motion,11 and measurements
of trunk flexibility have been used frequently to make
diagnostic, prognostic, and therapeutic decisions.12,13

There is great disagreement as to the best method for
assessing spinal motion. Weingarden14 concluded that it
was "an age old, first rate example of diversity of ap-
proaches, lack of uniform interpretation, poor commu-
nication, and general confusion." Techniques for mea-
suring spinal motion include the Schöber skin distraction
method15 and its various modifications,16,17 the flexi-
curve method,18 the inclinometric technique,19 a combi-
ined flexitube and hydrogoniometer,20 photometry,21,22
and radiographic technique.23,24,25,26 Most of these
methods have some degree of limitation in terms of
either reliability, accuracy, or invasiveness, and many
are only capable of measuring motion in one plane.
They only provide static measurements, resulting in a
single value of the end range of motion (ROM). Marras
and Wong27 noted that subjects with LBP showed an
inability to move and exert forces about their body
easily, resulting in the motion being slow and con-
trolled. It would appear beneficial to investigate dy-
namic motion characteristics.

With advancements in technology, new instruments
have been developed that are capable of assessing dy-
namic motion.6,15,21,24,34,35,44 Some of these systems
have been used to compare the motion of the normal
and LBP population, and Dvorák et al13 used one of
these systems to examine the active and passive ROM of
the lumbar spine in the normal population. There has

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Device status category: 9.
Table 1. Age and Sex Stratification of Study Population

<table>
<thead>
<tr>
<th>Age Range (yr)</th>
<th>Males</th>
<th>Females</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>20-29</td>
<td>29</td>
<td>30</td>
<td>59</td>
</tr>
<tr>
<td>30-39</td>
<td>25</td>
<td>20</td>
<td>45</td>
</tr>
<tr>
<td>40-49</td>
<td>20</td>
<td>20</td>
<td>40</td>
</tr>
<tr>
<td>50-59</td>
<td>21</td>
<td>20</td>
<td>41</td>
</tr>
<tr>
<td>60-70</td>
<td>8</td>
<td>10</td>
<td>18</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>103</strong></td>
<td><strong>100</strong></td>
<td><strong>203</strong></td>
</tr>
</tbody>
</table>

been no extensive study into the normal dynamic motion characteristics of the lumbar spine. The aim of the present study was to assess the ability of a triaxial potentiometric system to study spinal motion characteristics and to use this system to form a database of dynamic spinal motion, from which normal parameters of motion and the factors affecting this motion could be defined. This would form a reference with which data from LBP patients could be compared.

## Methods

**Population Examined.** Two hundred three subjects with no current history of LBP, no history of major spinal trauma, and no history of backache within the past 6 months were studied (the age and sex stratification are shown in Table 1). Of the subjects measured, 71% had no recollection of any LBP in their lifetimes. Of those noting a history of LBP, 61% stated that this episode occurred 5 years previously. Occupations varied; 29% classified their profession as sedentary, 55% as manual, and 16% as heavy labor.

**Measurement Equipment.** All measurements were performed using a computerized triaxial potentiometric system, the CA-6000 Spinal Motion Analyser (Orthopedic Systems Incorporated, Hayward, CA). This system was capable of objectively measuring spinal motion in three dimensions. It consisted of a linkage arm that incorporated six high precision potentiometers—three oriented in the sagittal plane to allow the determination of anteroposterior flexion-extension, two in the frontal plane to detect lateral bending, and one in the transverse plane to measure axial rotation (Figure 1). As the subject moved, the resistance of the potentiometers changed; this change was sampled at a frequency of 10 Hz via an analogue-to-digital converter and was interpreted through a personal computer into an angular measurement that was displayed graphically as a curve of angle against time. The computer output these data as a series of angular measurements. These angular measures were analyzed by a computer program written in QBasic, which, using a knowledge of the sample rate and the angular displacement, calculated the velocity characteristics.

**Test Procedure.** The study was approved by the local ethical committee, and all subjects gave informed written consent and completed a brief questionnaire detailing age, sex, height, weight, etc. Testing was performed with the subject barefoot and minimally clothed. The spatial linkage arm was attached to the subject via two harnesses—one positioned around the chest at the level of the thoracolumbar junction and the other around the pelvis at the level of the posterior superior iliac spines (Figure 2). Each subject was asked to stand looking straight ahead with the feet 0.2 m apart, and the potentiometers were set to this resting posture. A series of three unconstrained movements were performed at the subject’s preferred pace, in each plane of motion, to their limit of motion. Before recording, subjects performed a trial movement in each plane of motion to ensure comprehension of the test procedure. The movements were performed in a set sequence of rotation, lateral flexion, and flexion-extension (turning movements were always performed first to the right and then to the left).

**Accuracy.** The accuracy of the system was established by a series of tests against a vertical calibrated engineering mill with an adjustable head. Connectors were designed to allow the attachment of the link arm to the mill. Motion in each plane of movement was tested at increments of 5° from the neutral position.

**Repeatability.** To determine the inter- and intraoperator repeatability, 10 subjects (nine men, one woman; mean age, 35 years; range, 22–54 years) underwent a series of measurements using this system during a 3-day period. Assessments were performed by a senior physiotherapist and a clinical engineer, both familiar in skin surface marking techniques for the spine and both trained in the use of the equipment. Measurements were taken at the same time each day to avoid

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![Figure 1. The linkage arm of the CA-6000 Spinal Motion Analyser.](image-url)
Normal Motion Characteristics in the Lumbar Spine * McGregor et al 2423

Looking at the position, referred to as a Before plane, the rotation, in the vertical plane, is leftward.

Figure 2. Positioning of linkage arm and harnesses on a subject.

...errors caused by diurnal variations and on consecutive days to eliminate errors induced by subject fatigue and learning. The procedure as outlined was performed at each measurement session, and the choice of examiner at each session was random. Measures of intraoperator repeatability were obtained from repeated measures performed by the senior physiotherapist.

Analysis. An example of a typical graphical output for a flexion-extension test is shown in Figure 3. For all of the motion curves generated from each test, initially the maximum ROM was determined from the apex of each curve. Each output curve was divided into its two principal components, namely left and right rotation and lateral flexion, respectively, and flexion and extension. Each component was divided into two phases: a descent phase, taken as the interval from the upright position to the 90° point of full ROM, and an ascent phase, taken as the interval from the 90° point of full ROM to the upright position. For each of these phases, the mean velocity was calculated. The results were averaged over the three tests. The 90° point of full ROM was chosen because the remaining 10° of motion appeared to signify a turning period, where some subjects attained their maximum motion in one plane and returned to the upright position, and others attained their maximum ROM and briefly maintained this position. Because of these inconsistencies, this aspect of the curve was largely ignored.

Statistical Analysis. The statistical analysis was performed using the statistical package Stata (Stata Corp., College Station, TX) on a personal computer. The normal data were examined using analysis of variance (ANOVA), Mann Whitney U tests, and stepwise multiple regression analysis techniques, and using a significance level of 0.05. The inclusion of categorical data into the regression model was achieved using the methods described by Altman, and an analysis of covariance was done to investigate the interaction effects of the main factors identified in the multiple regression analysis. The data generated from the calibration testing were analyzed using simple linear regression, and repeatability was assessed using Bland and Altman’s mean difference technique.

Results

Calibration

The results of the calibration testing revealed excellent accuracy, with virtual unity between the engineering

Table 2. Repeatability of the CA-6000 in Determining Range of Motion

<table>
<thead>
<tr>
<th>Motion</th>
<th>Inter</th>
<th>Intra</th>
<th>Mean Difference ± SD</th>
<th>ICC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flexion</td>
<td></td>
<td></td>
<td>2.4° ± 3.3</td>
<td>0.94</td>
</tr>
<tr>
<td>Extension</td>
<td></td>
<td></td>
<td>1.1° ± 4.5</td>
<td>0.90</td>
</tr>
<tr>
<td>Left lateral flexion</td>
<td>Inter</td>
<td>Intra</td>
<td>-1.8° ± 4.3</td>
<td>0.91</td>
</tr>
<tr>
<td>Right lateral flexion</td>
<td>Inter</td>
<td>Intra</td>
<td>-0.5° ± 3.8</td>
<td>0.78</td>
</tr>
<tr>
<td>Left rotation</td>
<td>Inter</td>
<td>Intra</td>
<td>-1.0° ± 5.2</td>
<td>0.47</td>
</tr>
<tr>
<td>Right rotation</td>
<td>Inter</td>
<td>Intra</td>
<td>-0.4° ± 5.9</td>
<td>0.33</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>-1.0° ± 4.7</td>
<td>0.68</td>
</tr>
</tbody>
</table>

SD = standard deviation; ICC = intraclass correlation coefficient; Inter = interoperator repeatability; Intra = intraoperator repeatability.
mill and the CA-6000. This was confirmed by regression analysis in all planes of motion. The values obtained from the analysis agreed with those of Schuit et al.\textsuperscript{42}

**Repeatability**

Repeatability was assessed by estimating the mean difference between measures and the standard deviation of this measure of difference using the technique of Bland and Altman.\textsuperscript{6} Intraclass correlation coefficients were calculated to allow for comparisons with other published techniques. The results are summarized in Table 2 and show that the mean differences between the measures obtained by the two examiners and by the same examiner were low. None of the differences were statistically significant. Rotation demonstrated poorer repeatability than flexion—extension or lateral bending. These values are slightly better than those obtained by Petersen et al.\textsuperscript{16} using the same equipment.

The repeatability of the velocity measures were calculated, and the results of anteroposterior flexion-extension are summarized in Table 3, with similar values being attained in lateral flexion and rotation. These values showed slightly greater variation than the ROM values.

**Range of Motion Data**

The data obtained from the normal subjects were initially grouped into 10-year-age intervals, and the mean and standard deviation (SD) were calculated for each aspect of motion. The ROM measurements are summarized in Table 4, and the velocity characteristics are found in Tables 5-7.

Closer examination of the ROM results reveals that age and sex differences exist. The effects of sex were considered first, and significant differences (P < 0.05) were found in all planes of motion, except for lateral flexion to the right. Differences were found between age groups, with a trend of gradual reduction of motion with age, as shown in Figure 4. This apparent trend was investigated using ANOVA, which revealed significant differences between groups. The degree of age effect varied depending on the plane of motion assessed. Maximum extension appeared to be the movement most severely affected by age, with significant differences between each decade. This contrasted with flexion, where there was an initial reduction in motion after 30 years of age, but motion was maintained, and a further reduction was seen after 50 years of age. Changes in lateral flexion ROM did not occur between the 20-29 and 30-39 age groups, but after subjects exceeded 40 years of age, a pattern of significant reduction in ROM occurred at each decade. No consistent trend was seen between left and right rotation; in right rotation, a significant reduction in ROM occurred with each decade, but in left rotation, no significant age effects were identified.

To determine the strength of the relationship between age and ROM, linear regressions were performed on the data. These regressions revealed a weak relationship and showed considerable individual variation, as seen in Figure 5. This suggests that although age has a significant effect on ROM, this can account for only part of the variation seen in the normal population.

**Velocity Data**

A very different picture was seen when the velocity characteristics were considered. No clear differences were seen between men and women, although there was a tendency for women to move at slightly faster velocities than men. This difference was only significant during rotational movements. Age had no definite effect, and a pattern of reduced velocity with age was not
Table 5. Mean Velocity Characteristics (degrees/second) of the Lumbar Spine in Flexion–Extension

<table>
<thead>
<tr>
<th>Age (yr)</th>
<th>Sex</th>
<th>Flexion Descend</th>
<th>Flexion Ascent</th>
<th>Exterior Descend</th>
<th>Exterior Ascent</th>
</tr>
</thead>
<tbody>
<tr>
<td>20–29</td>
<td>M</td>
<td>33.7 ± 10.9</td>
<td>51.5 ± 18.6</td>
<td>28.9 ± 18.4</td>
<td>31.8 ± 15.7</td>
</tr>
<tr>
<td>F</td>
<td></td>
<td>26.8 ± 10.5</td>
<td>51.1 ± 17.1</td>
<td>26.4 ± 16.3</td>
<td>28.8 ± 16.4</td>
</tr>
<tr>
<td>30–39</td>
<td>M</td>
<td>32.4 ± 12.5</td>
<td>45.6 ± 16.2</td>
<td>24.1 ± 14.5</td>
<td>24.5 ± 11.4</td>
</tr>
<tr>
<td>F</td>
<td></td>
<td>35.1 ± 13.2</td>
<td>46.8 ± 15.4</td>
<td>32.7 ± 16.0</td>
<td>32.2 ± 15.6</td>
</tr>
<tr>
<td>40–49</td>
<td>M</td>
<td>33.6 ± 15.7</td>
<td>44.6 ± 16.7</td>
<td>22.1 ± 15.1</td>
<td>25.6 ± 16.2</td>
</tr>
<tr>
<td>F</td>
<td></td>
<td>33.7 ± 10.5</td>
<td>45.0 ± 15.2</td>
<td>27.3 ± 18.9</td>
<td>36.8 ± 17.7</td>
</tr>
<tr>
<td>50–59</td>
<td>M</td>
<td>33.4 ± 12.2</td>
<td>45.0 ± 18.6</td>
<td>24.5 ± 14.6</td>
<td>30.6 ± 10.1</td>
</tr>
<tr>
<td>F</td>
<td></td>
<td>28.2 ± 8.6</td>
<td>43.3 ± 18.0</td>
<td>24.3 ± 13.7</td>
<td>25.7 ± 13.1</td>
</tr>
<tr>
<td>60–70</td>
<td>M</td>
<td>22.3 ± 9.1</td>
<td>28.1 ± 9.1</td>
<td>12.6 ± 7.1</td>
<td>20.1 ± 8.7</td>
</tr>
<tr>
<td>F</td>
<td></td>
<td>17.1 ± 16.1</td>
<td>33.0 ± 12.7</td>
<td>16.1 ± 10.7</td>
<td>25.6 ± 15.8</td>
</tr>
</tbody>
</table>

always seen. Age appeared to have little or no influence on rotational velocity characteristics and lateral flexion. Age had some effect on anteroposterior flexion–extension, particularly during mean flexion ascent and mean extension descent; this was apparent only after 40 years of age.

Multiple Regression Analysis

It appeared from this initial examination of the data that more complex analysis techniques were required to identify factors that have an important effect on motion and that a combination of factors may affect motion. The effect of a variety of factors, including age, sex, body mass index (BMI), occupation (graded as sedentary, manual, and heavy labor), and past history of LBP (any previous recollection of LBP), on motion characteristics were examined using multiple regression analysis. An analysis of covariance was performed to investigate the interaction effects of these variables. Initially considering ROM, the results are summarized in Table 8.

The results showed that occupation and past history of LBP had no influence on any of the ROM values. Although factors have been identified that have a significant effect on ROM, these vary according to the plane of movement being analyzed. The analysis of covariance revealed interactions between some of the variables considered. In flexion, a significant interaction between sex and BMI was noted, which improved the strength of the model. In extension, an interaction between age and BMI suggested that age and sex were not important as independent explanatory variables in the prediction of ROM of extension. There were no significant interactions identified for rotation or right lateral flexion, although in predicting left lateral flexion, an interaction between sex and BMI was identified. All of the equations had low $r^2$ values, suggesting that although we have identified certain factors that affect ROM, these factors only account for a small proportion of the variation seen between individuals. This indicates that attempting to predict normal ROM with any degree of accuracy will be difficult.

Prediction of normal velocity characteristics is not easy, with fewer factors affecting mean velocity identified. The only consistent factor identified was ROM, and this was only a weak relationship. The results of the analysis on anteroposterior flexion–extension are summarized in Table 9.

Figure 4. Normal range of motion of anteroposterior flexion–extension by age.
Table 8. Factors Found to Have an Influence on Normal Ranges of Motion From Multiple Regression Analysis

<table>
<thead>
<tr>
<th>Age</th>
<th>Sex</th>
<th>BMI</th>
<th>Job</th>
<th>Previous Low Back Pain</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flexion</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.17</td>
</tr>
<tr>
<td>Extension</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.26</td>
</tr>
<tr>
<td>Left lateral flexion</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.20</td>
</tr>
<tr>
<td>Right lateral flexion</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.18</td>
</tr>
<tr>
<td>Left rotation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.08</td>
</tr>
<tr>
<td>Right rotation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.05</td>
</tr>
</tbody>
</table>

* p < 0.01
† p < 0.001
‡ p < 0.005
BMI = body mass index.

Table 9. Factors Identified From the Multiple Regression as Having an Affect on the Velocity Characteristics of an Anteroposterior Flexion-Extension Test

<table>
<thead>
<tr>
<th>Age</th>
<th>Sex</th>
<th>Range of Motion</th>
<th>BMI</th>
<th>Job</th>
<th>Previous Low Back Pain</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean flexion descent</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.16</td>
</tr>
<tr>
<td>Mean flexion ascent</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.16</td>
</tr>
<tr>
<td>Mean extension descent</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.19</td>
</tr>
<tr>
<td>Mean extension ascent</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.22</td>
</tr>
</tbody>
</table>

* p < 0.05
† p < 0.001
‡ p < 0.005
BMI = body mass index.

Discussion

The mobility of the vertebral column has interested researchers for over a century. There is controversy as to the best method of assessing spinal mobility, with existing methods being based on widely differing principles and with many only providing coarse descriptions of movement that are often time consuming or lack uniformity. In clinical and research work, it is important that individual observations are reliable and that the possible errors associated with a method of measurement are known. Numerous techniques for assessing spinal ROM have been documented in the literature, and the accuracy and repeatability of these techniques has been the subject of investigation over the years.

Reynolds stated that the method used to measure motion should be simple, quick, and repeatable. Radiography was believed to be the most suitable method for determining spinal motion, but this technique is limited because it is time consuming, expensive, and involves radiation exposure. The limitation of assessing motion using the fingers-to-floor technique has been well documented. The modified Schöber technique and the inclinometric method have been popularized, although there is disagreement as to which is the best method. The major limitations of these techniques are that they are of a static nature and that the majority are capable of measuring motion in only one plane.

This study has shown that there are instruments capable of measuring motion dynamically and in all planes of movement. Our investigations on a potentiometric system have shown it to be an accurate and repeatable method of assessing spinal motion statically and dynamically and agrees with the findings of Dvorák et al., who studied the cervical spine using this system. We have used this potentiometric system to form a database of the normal dynamic motion characteristics of the lumbar spine.

There have been few detailed studies of normal spinal motion, and those that have been performed have yielded variable results, partly because of differences in the consistency and accuracy of the methods used. Tanz was the first to identify sex differences and a decrease in motion with age, although his work noted that motion loss at the age of 35 years was not significant. The subsequent work of Loeb did not entirely agree with these findings, identifying a reduction in motion with each decade in flexion and extension and sex differences where women exhibited greater ROMs than men. Macrè and Wright disagreed and showed that men had greater ROMs than women. In 1971, Moll and Wright investigated flexion, extension, and lateral flexion and similarly identified a striking decrease in mobility with age and sex differences in each plane of motion, with men exhibiting more anteroposterior flexion–extension than women and women having greater ranges of lateral flexion. Hilton et al concluded that at all ages and in both sexes there is a wide range of total mobility, a thought echoed by Fitzgerald, who noted that variability in each decade generally increases in the older age groups.
Our study revealed that age had a significant effect on all planes of motion, but this effect did vary for each movement. When the strength of this relationship was tested using regression analysis, the influence of age on motion was found to be weak, indicating that age alone could not account for the variability seen; this finding agrees with the study by Buchalter et al. Similarly, the ratio of sex differences were identified, with men showing more flexibility than women in all planes except rotation. This agrees with Dvorák et al., who studied motion in the lumbar spine. Multiple regression analysis revealed that occupation and previous history of LBP have no effect on motion parameters, which contrasts with the findings of Burton and Tillotson. The BMI was found to influence flexion, extension, and lateral flexion, which agrees with Domján et al. From the analysis it can be seen that there is considerable variation within the normal population, suggesting that it is difficult to predict motion characteristics with any degree of accuracy.

The velocity characteristics showed even greater variability, with the ROM being the only consistent predictive factor. Trends seen in velocity characteristics varied greatly depending on the motion examined. No previous study has investigated normal velocity characteristics of the lumbar spine so comparisons cannot be made.

The range of normal data suggests that measures of motion may not be very sensitive measures of impairment. In a preliminary report, McGregor et al. noted that the mean behavior between the normal and LBP population differed significantly. There was great variability within the two groups and overlap in the data from individual subjects. These dynamic measures of motion are thought to be of greater importance in sequential measurements in the assessment of outcome, and current investigations are studying the effects of therapeutic intervention on dynamic spinal motion.

Conclusions

It is possible to make accurate and repeatable measurement of the dynamic motion characteristics of the lumbar spine in all planes of motion using a triaxial potentiometric computerized analysis system.

A database of normal values of motion has been generated, and from this, it can be seen that there is widespread individual variation. We have been able to identify certain factors that have an influence on spinal motion. These factors, although statistically significant only explain a small proportion of the variance in ROM and velocity.

Acknowledgments

The authors thank the Frances and Augustus Moody National Foundation and the F. H. Muirhead Trusts for their support of this work. The authors also thank Dr. Edward Draper for his assistance during the calibration and repeatability testing and Ms. Justine Hollyer for her statistical advice.

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iclinometer methods for measuring lumbar flexion and exten-

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