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ORIGINAL ARTICLE

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Segmental vertebral motion in the assessment of neck range of motion in whiplash patients

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Abstract The purpose of this study was to obtain comparative data concerning the relative contribution of segmental cervical vertebral motion to the cervical range of motion (ROM) in whiplash and healthy subjects in an effort to evaluate the usefulness of X-ray analysis in future forensic and research efforts. Each subject's neck ROM was measured with an optoelectronic system and also by X-ray measurements of the angular rotation in flexion and extension. The X-rays were examined to calculate the angular movement in the sagittal plane of each of the functional units C2–C3 to C6–C7. The chronic whiplash subjects showed reduced total neck range in all directions as compared to healthy subjects ($p<0.001$). There was a reduced total angular rotation from flexion to extension between these two groups ($p<0.01$), but no significant difference, however, between chronic whiplash subjects and controls in the percentage contribution of each of the functional units C2–C3 to C6–C7 to this rotation. This data will now allow a design of trials where healthy subjects are asked to simulate restricted neck ROM while undergoing optokinetic and X-ray evaluation of segmental vertebral motion. We will be able to determine if simulators produce a similar pattern to chronic whiplash and healthy, non-simulating subjects, and thus determine if, at least for forensic and research purposes, this technique is useful in validating reported restricted neck range.

Keywords Whiplash injuries · Neck pain · Range of motion · Cervical vertebra · X-ray

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Introduction

Previously in this journal, Dvir and Penso-Zabludowski [1] reported their findings in 26 normal subjects concerning the influence of the measurement protocol on the range and consistency of cervical motion in maximal vs. feigned limitation of range of motion. The authors concluded that while feigning of motion impairment is probably based on sensory input (probably a feeling of neck tension), the optimal testing protocol for detecting feigning should consist of within-direction repetitive cervical movements with eyes open. The relevance of this research to the medicolegal problem of whiplash is clear: the Quebec Task Force grading system for whiplash-associated disorders utilizes the criterion of restricted neck range of motion (ROM) in the diagnosis of grades 1 and 2 [2]. It is a common clinical practice, therefore, for clinicians and therapists to assess neck ROM in whiplash patients, and for neck ROM to be measured as a sign of progress. If this measurement is to remain relevant, there is not only a greater need to assess its value in prognosing and evaluating recovery, but especially in medicolegal cases involving exaggeration or simulation of restricted ROM. To address this problem, we first considered that measuring segmental vertebral motion may be more helpful than total ROM. Specifically, we set out to determine if the percentage relative contribution to restricted neck range from each functional unit (two contiguous vertebrae) in chronic whiplash patients is different from healthy controls.

Flexion-extension radiography has been in clinical use for over 50 years to detect abnormal segmental motion in the spine [3], with a number of methods by which to

examine relative rotation between contiguous vertebrae [4, 5, 6, 7]. Dvorak et al. [7] have shown, for example, that measurement of angles between adjacent vertebrae is a relatively straightforward procedure with high inter-examiner reliability, and Frobin et al. [8] have provided a database of normal rotation and translation motion as well as showing a low measurement error with these techniques.

Methods

Subjects

Subjects were recruited in a manner that would create a relatively homogeneous cohort. All whiplash subjects were recruited from insurance claim files. An insurance company physician was asked to provide claimants with an opportunity to enter into our study involving a neck X-ray. We asked that all those claimants referred to our study had a diagnosis of WAD 1 or 2 after their collision, were 18–50 years old, had ongoing (chronic) pain after a rear-end collision between 6 and 12 months earlier, and were awaiting some form of compensation. The subjects were screened by the authors based on Quebec Task Force recommendations to confirm they had no findings to suggest injuries to the spinal cord, peripheral nerves, or fractures [2]. We excluded subjects with radiographic evidence of spondyloarthropathy, rheumatoid arthritis, congenital disorders, or significant X-ray finding such as spondylolisthesis. Signs of degenerative disc changes were not an exclusion criteria, particularly as these signs are common in after 35 years of age . Healthy (control) subjects were recruited by advertisement and had similar age and X-ray restrictions, with no prior known history of neck injury and no recall of neck or dorsal spine pain in the last 12 months. We did not record the physical examination findings at the screening examination, but noted that the examiner found no objective neurological findings as in whiplash cases. As the purpose of the examination was to obtain baseline X-ray segmental motion measurements, we were less interested in the clinical findings of the whiplash subjects, so long as we had a relatively homogeneous population in terms of age, collision type and diagnosis for the whiplash group.

This study was conducted according to the ethics approval requirements as per the local policy at the study initiation, and each participant provided written, informed consent after the procedures of the study were explained. Participants were not told the specific purpose of the study, so that they would not focus on the range of motion portion, but rather the focus was placed on the X-ray component of the study, and the range of motion measurement was treated as a routine procedure. We were informed that the subjects had initially received treatment, in most cases with a soft collar and medications (analgesics), but we were not given any specific details of the treatment. We also collected minimal clinical information on the whiplash subjects, as it was not our intent to determine any particular relationships between neck ROM and clinical data. A future study will be evaluating this question.

ROM measurements

In order to confirm that the chronic whiplash subjects were typical of other whiplash populations in having a reduced neck ROM, each subject first underwent measurement of neck range in the directions of forward flexion, extension, lateral rotation to each side, and lateral flexion to each side. We utilized the Elite video system for measuring motion of these markers, chosen because of our familiarity with its use, accuracy, reliability, and precision. The procedure is quite different from usual clinical practice (and we did not intend to mimic clinical practice in this respect).

For the optokinetic ROM measurements, the subjects were seated comfortably in the center of the laboratory, with markers applied to 7 relevant anatomical reference points: forehead, crown, occiput of head, bilateral acromions, C7 prominence, and the region of maximal thoracic kyphosis in the seated posture (see Fig. 1). Located around the subject there were 4 cameras at a distance of about 2.5 m which tracked the movement of the markers. A computer program calculated the marker trajectories, from which the spatial angular motion of the head relative to the thorax can be computed. The subject was asked to make each movement six consecutive times, starting with right lateral flexion and ending with extension, the eyes closed in order to avoid visual fixation on specific targets on the walls. The maximal value for each of the repetitions in each directions was then retained to determine neck range.

X-ray analysis

To obtain measurements of the percentage contribution of the functional units C2–C3 through C6–C7 in healthy subjects and in patients reporting neck pain in the setting of motor vehicle collisions, we utilized a protocol based on Dvorak et al. [7] and Frobin et al. [8] to reliably quantify the magnitude of segmental movement patterns. Previous pilot efforts had confirmed a high inter-examiner reliability, and for rotational motion measurement errors of less than 2° [9]. The parameters describing rotational motion were derived from X-rays obtained in a fashion that matched typical clinical practice. The subject was radiographed in a standing position, first in maximum head and neck flexion, then in maximum extension. We chose active motion in order to again typify normal clinical practice such as how X-rays are commonly taken in emergency rooms. For the X-ray analysis of motion at each segmental pair of vertebrae from C2–C3 to C6–C7, we used standard flexion and extension lateral x-rays views. The analysis of the X-rays traced on paper the contours of the cervical vertebrae in flexion. Then the extension X-ray was superimposed on the tracing, and a line drawn on the tracing paper down a side of the X-ray (see Fig. 2). With the two images (the extension X-ray and the flexion X-ray tracing) overlapping exactly over C7, the extension X-ray was then rotated in order that the two C6 vertebrae overlapped and matched. Another line was traced along the same side of this X-ray. The angle between these two lines corresponds to the angle variation between the two images of the vertebrae on the moved film in respect to the fixed X-ray. When all 7 vertebrae had been

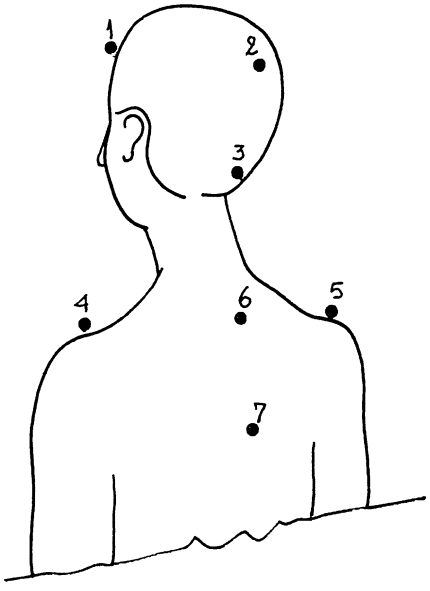

Fig. 1 Positioning of markers for head ROM measuring

superimposed and 7 lines traced (see Fig. 3), the image was scanned and analysed by the software program.

We chose the functional units C2–C3, C3–C4, C4–C5, C5–C6, C6–C7 because the images of C1 and T1 are often not readily visible on standard films. Once the absolute rotation angle was known for each vertebral pair, the total angular rotation Σ(C2–C7) for all pairs combined was calculated from the sum of these. Then, the percentage contribution of each pair from C2–C3 to C6–C7 was calculated by the following formula:

$$[(C_n - C_{n+1})/\Sigma(C2 - C7)] \times 100$$

where Σ(C2–C7) is the total angular movement in degrees summed between C2 and C7 and $C_n - C_{n+1}$ is the angular movement in degrees by each functional unit composed by vertebra *n* and vertebra *n+1*.

Statistical analysis

We used an unpaired *t*-test (alpha=0.05) to compare range of motion and segmental motions for each group. From an initial analysis, we found that the mean total ROM and mean percentage contribution of each functional unit was not different between genders or the age groups 20–30, 30–40, and 40–50 years (consistent with the findings of Kristjansson et al. [3] and Frobin et al. [8]), so we grouped both genders and all ages together, correcting *p*-values for multiple comparisons.

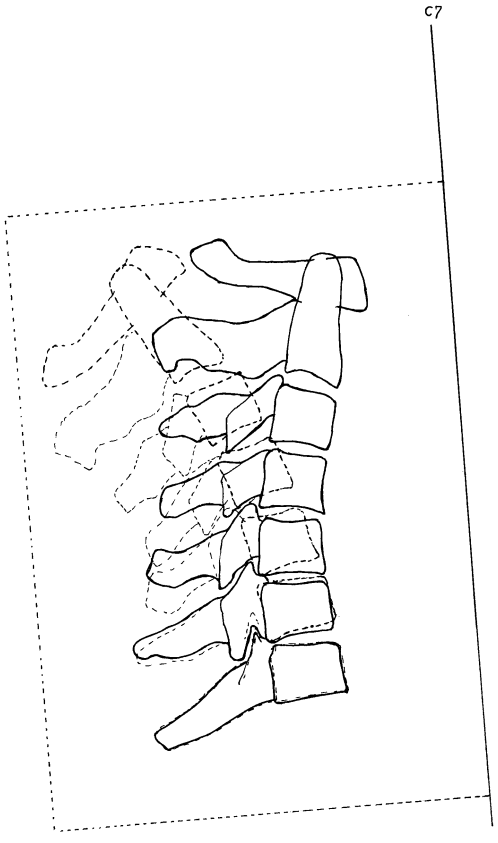

Fig. 2 Super-imposition of extension x-ray (*dotted*) on the tracing paper with the flexion spine image, and tracing of the first line

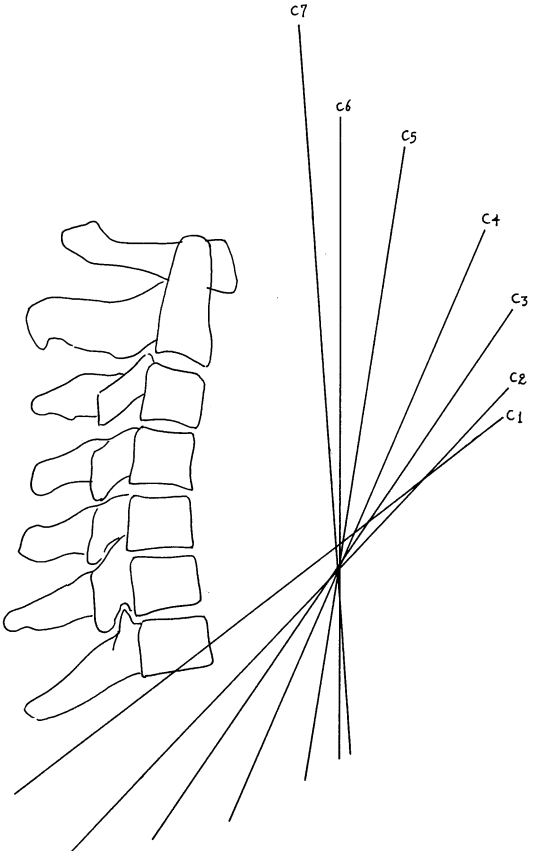

Fig. 3 Aspect of tracing paper at the end of process with the 7 lines traced in correspondence of the super-position of each vertebra

Results

A total of 129 chronic whiplash subjects (73 males, 56 females, mean age=36.7±7.2 years) and 126 healthy controls (69 males, 57 females, mean age=31.9±7.2 years) were studied. All of the whiplash subjects had an initial reported diagnosis of WAD grade 1 and 2 and at the time of study did not have any neurological findings to suggest other injuries.

The ranges of motion for six directions for the chronic whiplash and control subjects are shown in Table 1. As expected, the chronic whiplash subjects showed a reduced range of motion in all directions compared to control subjects ($p<0.001$). The total angular rotation from flexion to extension as measured from X-ray analysis for the chronic whiplash subjects and controls is shown in Table 2. The mean total flexion to extension angular motion was 70.9±12.9° for whiplash subjects and 79.4 ±13.8° for normal controls ($p<0.001$). Note that the total angular rotation from the X-ray analysis of motion of C2–C7 is expected to be less that the combined flexion and extension range seen by optokinetic measurement because motion at other vertebral sites (C1 and T1) is not included in the X-ray analysis.

The mean percentage contribution of each pair from C2–C3 to C6–C7 to the total angular motion from C2-C7 from flexion to extension in both study groups is shown in

Table 1 Total range of motion in 6 directions in subjects with chronic whiplash (*N*=129, 73 males, 56 females, mean age=36.7±7.2 years) and healthy subjects (*N*=126, 69 males, 57 females, mean age=31.9±7.2 years)

Subject group	Flexion	Extension	Right lateral rotation	Left lateral rotation	Right lateral flexion	Left lateral flexion
Whiplash	52.6±12.7	50.1±14.1	62.7±13.9	62.4±15.1	36.9±7.1	37.7±6.6
Normal Controls	63.3±9.7	66.4±14.0	74.0±8.4	73.2±8.8	43.5±6.0	44.8±7.7
Corrected*P*-values	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Confidence interval (95%) for difference	−13.492 to −7.908	−19.766 to −12.834	−14.141 to −8.459	−13.857 to −7.743	−8.223 to −4.977	−8.867 to −5.333

Measurements obtained via optokinetic instrument Elite are expressed in degrees, mean±standard deviation.

Table 2. Although chronic whiplash patients had an overall absolute reduced range in motion from flexion to extension when compared to healthy (normal) controls, the percentage contribution of each functional unit from C2–C3 to C6–C7 showed no statistically significant differences between chronic whiplash subjects and controls. Assuming alpha set at 0.05, with the current sample sizes and variances, this study had the power (90% probability) to detect a true difference of 2% between means among chronic whiplash subjects and controls.

Discussion

Clinical experiments have significant relevance to the medicolegal problem of whiplash, particularly when simulation of injury is a concern. Dvir and Penso-Zabludowski [1] have developed a protocol for testing neck range of motion which aims at separating feigning from non-feigning subjects. Castro et al. [10] also published a clinical observation of the symptomatic outcomes of "placebo collisions" because of the concern of simulation and financial gain in low-velocity collisions in particular. Such works attract a great deal of attention partly because of their medicolegal implications [11, 12, 13]. We have shown in this study that chronic whiplash patients differed significantly in their total ROM, and in the angular motion of flexion to extension. This is not surprising and is in agreement with other studies [3, 14, 15]. We have also shown, however, that the segmental percentage contribution to the flexion-extension range in chronic whiplash patients was the same when compared to controls.

It should not be assumed that the observations here will apply to acute whiplash patients. Further, we do not specifically attribute restrictions in neck range of motion necessarily to the acute injury. There are many factors (including psychosocial, treatment approach, activity levels, etc.) which are thought to contribute to chronic neck pain, and these are also likely to influence neck range of motion.

There are sources of error with our measurement techniques. One source lies in using the full image of the vertebra and of superimposing the two images until their edges look coincident or at least parallel. We have evaluated this previously [9] and have shown that the error rate is about 1.5° in rotation, which compares well with other research findings [8]. The hand drawing obtained from contouring the vertebrae is used without attempts to correct for distortion from lateral tilt or axial rotation, and we do not correct for magnification effects, although magnification effects are greatest for vertebrae furthest from the beam centre, e.g., C1 and T1 vertebrae, which we did not use in this study. We also did not measure translational movement as done by Kristjansson et al. [3]. who were looking for ligamentous instability. Increased translation due to ligamentous laxity would not affect our overall measurements in rotation as ligamentous instability

Table 2 Angular motion of vertebral functional units C2-C3 to C6-C7 in subjects with chronic whiplash (*N*=129, 73 males, 56 females, mean age=36.7±7.2 years) and healthy subjects (*N*=126, 69 males, 57 females, mean age=31.9±7.2 years)

Subjects	C2–C3	C3–C4	C4–C5	C5–C6	C6–C7
Whiplash	9.7±2.8	14.4±3.7	16.9±3.8	16.8±4.4	12.7±5.2
	(13.9±3.9%)	(20.6±4.7%)	(24.0±4.3%)	(23.9±5.0%)	(17.6±6.0%)
Normal controls	10.0±3.0	15.7±3.5	17.9±4.0	18.9±4.6	16.2±4.9
	(12.9±3.3%)	(20.1±3.5%)	(22.8±3.3%)	(24.1±4.4%)	(20.2±4.5%)
Corrected*P*-values for difference in percentages	n.s.	n.s.	n.s.	n.s.	n.s.
Confidence intervals (95%)	0.108 to 1.892	-0.524 to 1.524	0.253 to 2.147	-1.363 to 0.963	0.090 to 2.710

Measurements of absolute angular motion for each functional unit C2–C3 to C6–C7 are shown in degrees, mean±standard deviation.
The mean percentage contribution of each functional unit to the mean total flexion-extension angular motion of C2–C7 is shown in percentage (%) below each absolute mean angular rotation per functional unit.

increases the ratio of translation to rotation by increasing the translation, not by reducing rotation [8]. It is also possible that chronic whiplash subjects and healthy subjects may differ in the percentage contribution of each functional unit C1–C2 and C7–T1. Future studies will address this possibility.

The question also remains whether simulators of restricted ROM will show this same pattern of percentage contribution of each functional unit C2–C3 to C6–C7. If they do not, then this is an objective measure by which to detect simulation or exaggeration of restricted range. We assumed in this study that only a minority, if any, of the chronic whiplash patients were exaggerating restriction in ROM. In this study we found no difference, suggesting either few or no exaggerators in the whiplash group or that measuring percentage contribution of each function unit is not a means by which to detect simulation.

More studies are needed. The next step is to have a group of healthy subjects attempt to feign (or exaggerate) restricted neck ROM and undergo similar analyses. It will also be of interest to examine acute whiplash patients (grade 1 and 2 WAD), and to compare chronic non-traumatic neck pain patients to chronic whiplash patients.

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