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Increased Sagittal Plane Segmental Motion in the Lower Cervical Spine in Women With Chronic Whiplash-Associated Disorders, Grades I–II

A Case-Control Study Using a New Measurement Protocol

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Study Design. Case-control study comparing sagittal plane segmental motion in women (n = 34) with chronic whiplash-associated disorders, Grades I–II, with women (n = 35) with chronic insidious onset neck pain and with a normal database of sagittal plane rotational and translational motion.

Objective. To reveal whether women with chronic whiplash-associated disorders, Grades I–II, demonstrate evidence of abnormal segmental motions in the cervical spine.

Summary of Background Data. It is hypothesized that unphysiological spinal motion experienced during an automobile accident may result in a persistent disturbance of segmental motion. It is not known whether patients with chronic whiplash-associated disorders differ from patients with chronic insidious onset neck pain with respect to segmental mobility.

Methods. Lateral radiographic views were taken in assisted maximal flexion and extension. A new measurement protocol determined rotational and translational motions of segments C3–C4 and C5–C6 with high precision. Segmental motion was compared with normal data as well as among groups.

Results. In the whiplash-associated disorders group, the C3–C4 and C4–C5 segments showed significantly increased rotational motions. Translational motions within each segment revealed a significant deviation from normal at the C3–C4 segment in the whiplash-associated disorders and insidious onset neck pain groups and at the C5–C6 segment in the whiplash-associated disorders group. Significantly more women in the whiplash-associated disorders group (35.3%) had abnormal increased segmental motions compared to the insidious onset neck pain group (8.6%) when both the rotational and the translational parameters were analyzed. When the translational parameter was analyzed separately, no significant difference was found between groups, or 17.6% (whiplash-associated disorders group) and 8.6% (insidious onset neck pain group), respectively.

Conclusion. Hypermobility in the lower cervical spine segments in 12 out of 34 patients with chronic whiplash-associated disorders in this study point to injury caused by the accident. This subgroup, identified by the new radiographic protocol, might need a specific therapeutic intervention. [Key words: whiplash injuries, cervical spine, flexion–extension radiograph, rotational motion, translational motion, chronic] **Spine 2003;28:2215–2221**

Recent research into the mechanism of whiplash-type distortion injuries using modern technology has shown that the cervical spine may undergo a transient abnormal S-shaped motion during whiplash loading.[1–6] Abnormal increased segmental motions with concomitant sliding and compression in the facet joints before the total physiologic range of flexion–extension is reached has been documented.[1,3,5,6] As it has been difficult to identify any anatomic lesions in the cervical spine after low-speed car collisions in most symptomatic patients, it has been reasoned that this abnormal motion may be responsible for potential damage to the soft tissues of a cervical motion segment.[7] Clinicians believe that the presence, development, or progression of abnormal increased segmental cervical motions indicates a poor prognosis after motor vehicle collisions (MVCs).[8–10] However, no *in vivo* evidence demonstrates increased flexibility in the lower cervical spine segments in patients with chronic complaints after low-speed MVCs. It is therefore important to compare patients with whiplash-associated disorders (WAD) with both asymptomatic patients and patients with neck pain that have not been exposed to MVCs.

Flexion–extension radiography has been in clinical use for over 50 years to detect abnormal segmental motions in the spine.[11] A number of protocols for the cervical spine have been published that attempt to quantify the magnitude[12–15] and the quality of the motion by documenting inappropriate segmental movement patterns.[16–20] These protocols have enriched our understanding of the behavior of a spinal segment. However, it has been difficult to differentiate pathologic segmental motions from alterations that occur during the normal ageing process.[21] In addition, the measurement error of these protocols limits their validity.[22,23] Normal data for

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Table 1. Comparison of Demographic Characteristics

	WAD	IONP
Mean age in yrs (SD)*	29.3 (8.5)	31.6 (8.7)
Mean height in cm (SD)*	169.0 (4.7)	168.3 (5.8)
Median weight in kg (quartiles)†	62.0 (55.8–72.3)	66.0 (61.0–77.0)
Median working hrs/wk (quartiles)†	38.5 (0–40.5)	35.0 (7.0–44.0)
Median pain duration in mos (quartiles)†	14 (7.2–25.2)	13 (6.8–28.5)
Median mos elapsed since the MVCs (quartiles)	14 (8.5–24.5)	

No significant differences by *Independent *t* test and †Mann Whitney U test.
WAD = whiplash-associated disorders; IONP = insidious onset neck pain; MVC = motor vehicle collision.

Table 2. Inclusion and Exclusion Criteria

	Inclusion	Exclusion
General	1. Age: 16–48 yrs	1. Systematic diseases of any kind
	2. Employed or student	2. Personality changes
	3. Driving a car on a regular basis	3. Pregnancy
WAD	Prior to the crash	
	1. Healthy (no symptoms from the upper part of the body)	1. >1 crash/accident before the exam
	After the crash	
	2. WAD Grades I–II, as outlined in the QTF on WAD	2. Prone to get musculoskeletal symptoms prior to the MVC
	3. Symptoms for > 6 mos and <48 mos	3. Road accident of another kind than in a car
		4. Car crash in rural setting
IONP	1. Musculoskeletal symptoms from the upper part of the body including the neck	1. MVC or another type of injury
	2. Attends the primary health care for help	2. Symptoms of <6 mos duration and >48 mos
	3. The symptoms are on the scale slight–severe	3. Signs of radiculopathy in the arm(s)

WAD = whiplash-associated disorders; IONP = insidious onset neck pain; MVC = motor vehicle collision; QTF = Quebec Task Force.[40]

posteroanterior translational motion in the cervical spine were not available, rendering descriptions of the sagittal plane cervical motion patterns incomplete.

A new protocol that precisely documents rotational and translational segmental motion[24] is employed in this study. Motion data are independent of radiographic magnification and distortion as well as of patient alignment. For rotational motion, the measurement error amounts to less than 2°. For posteroanterior translational motion, it amounts to less than 5% of vertebral depth: for a vertebra of 15 mm depth this corresponds to 0.7 mm. Rotational and translational motion can be compared with a normal database on sagittal plane segmental motion.[24] Comparison of translational motion with the norm is performed in a fashion not confounded by variations of the magnitude of rotational motion in the individual case.

This study compares sagittal plane motion of segments C3–C4 and C5–C6 of two cohorts, women with chronic WAD, Grades I–II, and women with chronic insidious onset neck pain (IONP) with a normal database as well as among cohorts. The aim is to reveal whether women with chronic WAD, Grades I–II, exhibit radiologic evidence of abnormal segmental motion (hypo- or hypermobility) in the lower cervical spine. Comparison of the WAD with the IONP cohort is performed in order to better isolate potential, specific effects of the whiplash episode. As no criteria have been proposed to classify abnormal sagittal plane cervical motion, the study is explorative in nature.

■ Materials and Methods

Patients. Eighty symptomatic women participated after giving informed consent. They were divided into a WAD group (n = 41) and an IONP group (n = 39). Asymptomatic women recruited in a prior study served to give baseline data.[23] The symptomatic patients were recruited from doctors and physiotherapists in the Reykjavík metropolitan area over a fixed 7-month period. The patients were randomly allocated to the study according to Armitage and Berry.[25] Table 1 shows the demographic data and Table 2 shows the inclusion criteria. Ethical clearance for the study was obtained from the Icelandic Radiation Protection Institute and the Medical Ethics Committee at the University Hospital in Reykjavík.

Radiographic Examination. Digital radiography (Siemens, AG 1990 Flurospot H./Digital Fluro Radiography Software: VD 11) was used. All radiograms were taken in a lateral position, and the women sat in a standardized sitting position using fluoroscopic control for alignment. The height of the chair was electronically adjustable, which enabled each patient to sit with the feet positioned flat on the support with the hips and knees in 90° flexion. The patient's arms rested freely in the lap. Vertebrae C3–C6 appeared in all images, C2 and C7 in only a fraction of the images. Segmental motion analysis was thus restricted to segments C3–C4, C4–C5, and C5–C6.

The women underwent an assisted flexion–extension examination of the cervical spine. An examiner blind to the women's group placement performed all examinations. The examiner instructed the women to actively relax as much as possible in the head-neck-shoulder girdle area during the whole procedure. For the radiograms obtained in maximal flexion–extension positions, the examiner placed his left hand on the patient's head and the right hand on the patient's chin. Each woman was instructed to start the movement with the head, assisted by the examiner inducing slight forward inclination at occiput-C1. "Winding" of the cervical spine from above downwards, as described in the Arlen method, was then performed to maximal flexion.[13]

A vapocoolant spray (Fluori-Methane, Cramer Products, Inc., Gardner, Kansas) was used on the posterior aspect of the neck and shoulder girdle to relax the muscles. Six streams were applied, three on each side starting cranially/caudally and from the medial to the lateral aspect. After this, the examiner moved the patient's head and neck slowly further into maximal flexion. A radiograph was taken in this position. After 10 seconds' rest in the upright position, a similar procedure was used for the maximal extension position. The patient's mouth was slightly open to relax the hyoid muscle group. Six coolant

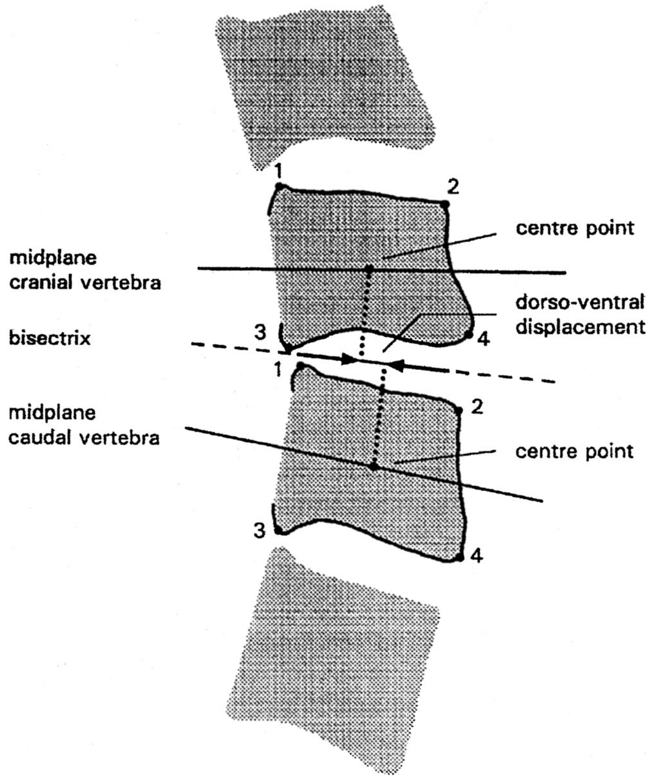

Figure 1. Definition of sagittal plane angle and displacement for a lower cervical motion segment. Corners 1–4 are located on the vertebral contour by a computer-aided algorithm. Vertebral midplanes pass through the midpoints between the ventral and dorsal corners. The sagittal plane angle is given by the angle between the midplanes. Perpendiculars are constructed from the vertebral center points onto the bisectrix between the midplanes. The sagittal plane displacement is given by the distance of the points where the perpendiculars intersect the bisectrix.

streams were applied from the hyoid bone to the clavicle, three on each side. The examiner supported the head slightly from beneath during the whole procedure until the maximal extension position was reached.

Measurement of Segmental Motion. The method is briefly summarized here; for details, refer to Frobin *et al.*[24] The new protocol determines the relative location and orientation of cervical vertebrae from conventional, sagittal views of the cervical spine. Vertebral contours are manually mapped and digitized. Computer programs subsequently define objective landmarks on the vertebral contours. Magnification and distortion in central projection are corrected for, and the sagittal plane angle and posteroanterior displacement are measured virtually uninfluenced by distortion with respect to axial rotation, lateral tilt, and off-center positioning of the vertebrae.

Figure 1 shows the (hand-mapped and subsequently digitized) contours that can be identified in the lateral radiographic image of cervical segments from C3 to C7. Corners 1 to 4 are objectively located on the outer contours of the vertebral bodies by a computerized algorithm. The center point is the geometric center of corners 1 to 4. The vertebral midplane is defined as a line running through the midpoints between corners 1 and 3 and 2 and 4, respectively. The angle between two vertebrae is derived from the angle between their midplanes. The angle is considered positive if the wedge opens anteriorly. Sagittal plane rotational motion (in short: "rotational motion") of a segment is defined as the difference of the angle in extension minus the angle in flexion and is quoted in degrees.

Computer programs construct perpendiculars from the center points of adjacent vertebrae onto the bisectrix between the midplanes. Posteroanterior displacement is defined as the distance between those points where the perpendiculars intersect the bisectrix. Thus, displacement is measured along a direction coinciding (in good approximation) with the midplane of the disc. Displacement is considered positive if the projection of the cranial center point is located anteriorly from the projection of the caudal center point. To correct for radiographic magnification and variation in stature, the displacement measured in millimeters is divided by the mean depth of the caudal vertebra. The mean depth is the mean of the distance between corners 1 and 2 and 3 and 4, respectively. Sagittal plane translational motion (in short: "translational motion") is the difference between displacement in extension minus displacement in flexion. Displacement and translational motion are dimensionless quantities.

For an individual, the range of rotational motion can be compared to a normal database derived from flexion–extension views of healthy, adult patients.[24] However, the large biologic variance in rotational motion in healthy patients means that such a comparison yields only limited information for classifying normal and abnormal rotational motion. In healthy patients, translational motion was observed to be linearly related to the rotational motion performed.[24] For segments C3–C4, C4–C5, and C5–C6, the translational motion per degree of rotation varies between gender and levels and is of the order of 0.008 deg^{-1}, *i.e.*, in the order of 0.8% of vertebral depth per degree of rotation. This established relation between rotational and translational motion offers the possibility of comparing the actual translational motion of a patient with a predicted normal value defined as "translation per degree of rotation in normals multiplied by degrees of rotation actually performed by the patient." In contrast to direct comparisons of motion range, the comparison between actual and predicted translational motion is independent of the range of rotational motion performed by the patient and thus not confounded by motivation or pain.

Data Analysis. For segments C3–C4, C4–C5, and C5–C6, the differences between rotational motion of the WAD group and the IONP group as well as the normal database were compared using the independent *t* test. The actually measured and the predicted translational motions for each segment in both groups were calculated and analyzed by the paired *t* test. Individual segments were also designated as hyper- or hypomobile with respect to rotation and translation. In the former case, the actual rotation had to differ by more than ±1.96 SD from the normal database, and in the latter case, the measured translation had to differ by more than ±1.96 SD from its predicted value. The patients were then classified into three classes: 1) normal = neither hypermobility nor hypomobility in any segment; 2) rotational hypermobility = rotational hypermobility in one or more segments but no translational hypermobility or hypomobility; and 3) translational hypermobility = translational hypermobility in one or more segments irrespective of rotational and translational motion in other segments. Hypomobility with respect to rotational or translational motion was not observed. The Fisher exact test compared the number of women with abnormal segmental motions across the two

Table 3. Comparison of Mean Rotational Motions in the Sagittal Plane (1 SD in Parentheses)

Segment	Group	n	Angular Values	Group Differences Values	Group Differences *P*	Dvorák *et al,* 1993†
C3–C4	WAD	34	19.3° (3.70)	3.50° (5.05)	<0.001*	18.5° (4.57)
	IONP	35	15.8° (3.96)			16.5° (2.51)
	WAD	34	19.3° (3.70)	4.10° (4.13)	<0.001*	
	ND	92	15.2° (4.27)			
C4–C5	WAD	34	21.1° (4.07)	2.60° (4.90)	0.01*	21.6° (5.15)
	IONP	35	18.5° (3.64)			19.3° (4.03)
	WAD	34	21.1° (4.07)	4.10° (5.14)	<0.001*	
	ND	95	17.0° (5.46)			
C5–C6	WAD	34	21.3° (4.69)	0.93° (5.98)	0.39	21.3° (5.49)
	IONP	34	20.3° (4.13)			16.8° (6.00)
	WAD	34	21.3° (4.69)	3.40° (6.15)	<0.001*	
	ND	92	17.9° (6.60)			

* $P < 0.05$ (independent *t* test).
† A trauma group and a degenerative group, respectively.[12]
WAD = whiplash associated disorders; IONP = insidious onset neck pain; ND = normal database.

symptomatic groups. The statistically significant level was set at $P < 0.05$ for all tests.

Results

Thirty-four patients in the WAD group and 35 patients in the IONP group met the measurement criteria for segmental analysis. Table 1 shows the similarity of the demographic variables in both groups. Table 2 shows the inclusion and exclusion criteria used. Table 3 summarizes the results when rotational motion between groups is compared. Table 4 summarizes the comparison of measured and predicted translational values across groups. Table 4 shows that comparisons of measured *versus* predicted translational motions within the C3–C4 and C5–C6 segments were significantly different in the WAD group and within the C3–C4 segment for the IONP group. The results of the Fisher exact test together with the raw values are presented in Table 5. Significantly more women in the WAD group had segmental rotational or translational hypermobility, according to the definition used (Figures 2 and 3) in this study or 35.3% compared to 8.6% in the IONP group. With respect to translational hypermobility alone, no significant difference was found between groups. No hypomobility was observed in the three segments analyzed.

Discussion

No formal criteria have been established for abnormal segmental motions of the spine. The increasing body of knowledge indicates that the translational parameter might play an essential role in such criteria. *In vitro* studies have found that an increased neutral zone, which is an increased segmental displacement around the neutral spine position, is a more sensitive parameter for abnormal increased segmental motion than the range of motion.[26–30] In addition to *in vivo* static flexion–extension radiographic views, cineradiographic motion analysis have also been used.[31,32] Such studies have focused on angular cervical motion patterns during continuous motion analysis in the sagittal plane[31,32] and the disproportion between rotational and actual translational motion[32] as described by Dvorák *et al.*[12] The methodology presented here introduces a new method of calculating abnormal sagittal plane segmental motions from static flexion–extension radiographic views of patients with neck pain.

As the rotational parameter has been found to be more variable and consequently more difficult to interpret,[20,22] the segmental translational parameter was also used in this study. A new precision measurement radio-

Table 4. Comparison of Mean Translational Motions in the Sagittal Plane (1 SD in parentheses)

Segment	Group	n	Translation, Actual*	Translation, Predicted*	Difference: Actual Minus Predicted*	Difference: Actual Minus Predicted†	Actual Versus Predicted Values *P*
C3–C4	WAD	34	−20.79 (5.69)	−18.51 (3.53)	−2.27 (6.29)	−0.43 (0.96)	0.04‡
	IONP	35	−17.07 (4.69)	−15.42 (3.88)	−1.65 (4.24)	−0.40 (0.96)	0.03‡
C4–C5	WAD	34	−19.73 (5.70)	−18.36 (3.40)	−1.37 (6.18)	−0.28 (1.02)	0.21
	IONP	35	−16.89 (4.65)	−16.35 (3.25)	−0.54 (5.11)	−0.16 (0.89)	0.54
C5–C6	WAD	34	−12.41 (5.94)	−10.49 (2.30)	−1.94 (4.95)	−0.36 (1.12)	0.03‡
	IONP	34	−11.26 (4.46)	−9.86 (2.04)	−1.40 (4.38)	−0.37 (1.09)	0.07

* In units of mean vertebral depth.
† In units of SD of the norm.
‡ $P < 0.05$ (paired *t* test).
WAD = whiplash-associated disorders; IONP = insidious onset neck pain.

Table 5. Fisher Exact Test of the Relationship Between Hypermobility and Normal Segmental Mobility

	Rotational	Translational	Normal	Total
WAD	6	6	22	34
IONP	0	3	32	35
Total	6	9	54	69
		Two-sided $P = 0.01$		

WAD = whiplash-associated disorders IONP = insidious onset neck pain.

logic protocol and criteria derived from a normal database were used for the comparison. The range of rotational motion and the actually performed translational motion as well as its predicted value, derived from the translational motion "per degree of rotation" in healthy patients, were analyzed.

Rotational motion of the segments C3–C4 and C4–C5 in the WAD group were significantly increased compared to both the IONP and the normal database. In segment C5–C6, no differences in rotational motion were found between WAD and IONP groups. However, significant differences were found when the WAD group

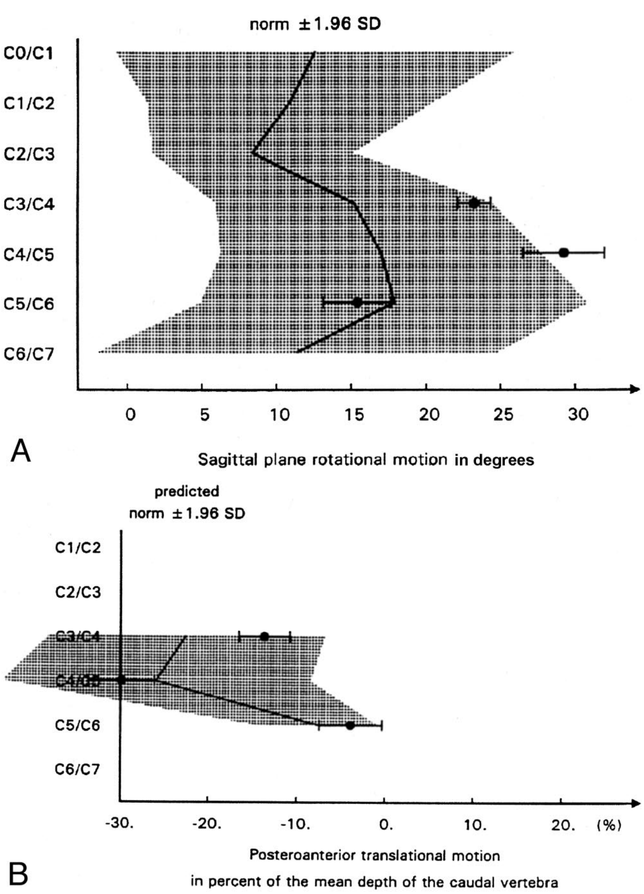

Figure 2. **A,** An example of documentation of rotational hypermobility in an individual case. The actual rotation in the C4–C5 segment differed by more than ±1.96 SD from the normal database. In this as well as following figures: solid line = normal mean; error bars = measurement errors (1 SD). **B,** The actual and predicted translational motion for the same individual for comparison.

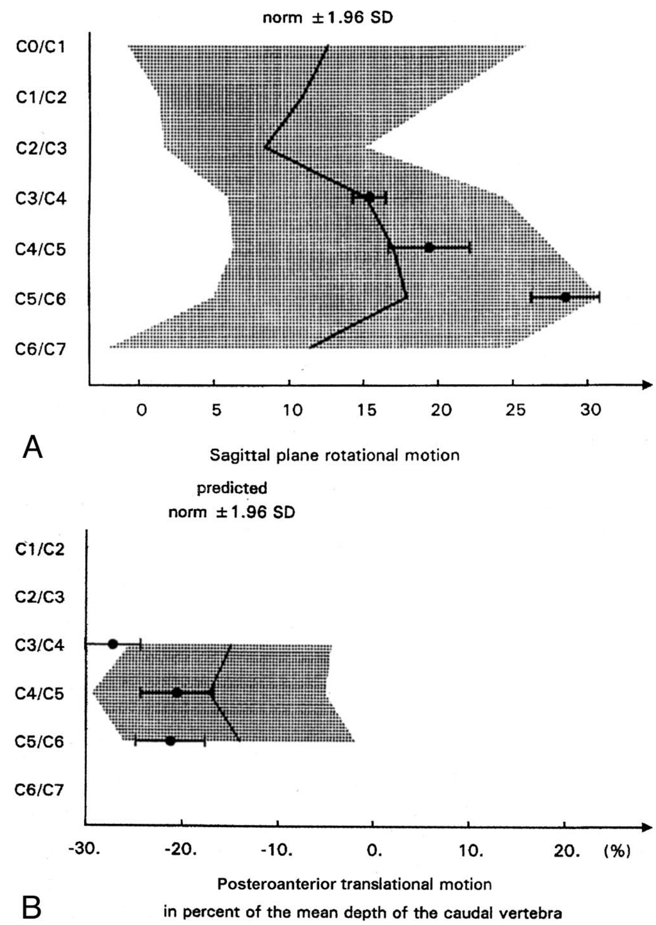

Figure 3. **A,** The actual rotational motion in an individual case. **B,** An example of documentation of translational hypermobility for the same individual. The actual translation in the C3–C4 segment differed by more than ±1.96 SD from its predicted (normal) value.

was compared to the normal database (Table 3). The difference between the actual and the predicted translational motion may be a sensitive parameter for detecting abnormal segmental motions in symptomatic patients (Figure 3). Six women in the WAD group and three women in the IONP group met the criteria for abnormal translational motion (Table 5). The women with chronic WAD in this study revealed significantly increased prevalence of combined rotational and translational hypermobility in the middle cervical spine segments compared to women with chronic IONP (Table 5). Clinically, it is very important to identify such a subgroup of chronic WAD patients to better tailor treatment interventions, but there is a general tendency to look on chronic patients as a homogenous group.[33]

In our opinion, the translational parameter as it is defined in this study is the most accurate parameter available to judge abnormal *in vivo* segmental motions in the spine. The results of this study must be interpreted accordingly. The between group rotational differences are more questionable due to the great variance in rotational motion as has been previously mentioned. However, this study was performed in a solid controlled manner. To avoid systematic error, random allocation to the study was used, and both the examiner and the radiographer were blind to the women's group. Besides, all women were treated in the same way by standardizing the sitting position, and a strict protocol was followed regarding the manual handling of the neck. The assisted examination was performed to minimize confounding factors like pain, muscle guarding, and lack of motivation of the patient. The methodology followed in this study therefore strengthens the likelihood that the between-group differences in rotational motions are of clinical importance.

The major limitation of this study is that only three segments were analyzed. The upper cervical spine segments are more commonly injured when the head and neck are in a flexed and a rotated position at the moment of the MVC.[34–36] Thus, one might speculate that some patient with chronic WAD, Grades I–II, may have abnormal increased segmental motion in the segments not analyzed in this study. Another limitation of this study is that it is cross-sectional. It is therefore not possible to know whether the differences in biomechanical variables observed differed from the onset of symptoms or whether the differences developed over time. A prospective longitudinal study including a bigger cohort where all cervical segments are analyzed must be conducted to address these limitations.

Subsequent increases in segmental motion have been correlated to soft tissue injuries of the spine.[30,36,37] The intervertebral disc is the most important structure preventing abnormal increased segmental translational motion.[21] The increased segmental motion found in some women with chronic WAD in this study, possibly due to occult or incomplete soft-tissue injuries not easily healed,[5,7,38] may be an important predisposing factor for their chronicity.[39] Classifying patients with WAD on the grounds of decreased or normal range of sagittal plane rotational motion[40] without considering the possibility of underlying abnormal increased segmental motions is misleading. The emphasis on range of rotational motion exercises in the acute phase[41,42] has to be modified according to the segmental mobility status of each individual patient.

The sagittal alignment of the cervical spine in the women in our study was also examined in another study.[43] The results of that study showed that the C4–C5 segment in the WAD group was in a significantly more flexed position compared to an asymptomatic group. The WAD group also exhibited a greater tendency towards a decreased lordosis in the lower cervical spine and a relatively increased lordosis in the upper cervical spine.[43] The aforementioned study and the result of this present study suggest that some patients with whiplash need a specific exercise therapy targeting the deep segmental muscles[44] to enhance proper segmental alignment and movement control of segmental motions[8,45] in the cervical spine. Further investigations are warranted as the findings in this study point to chronic injury in a subgroup of patients with chronic whiplash, Grades I–II.

■ Conclusion

To summarize, this case-control study used several measures derived from a new precision measurement protocol and a normal database to explore abnormal segmental motions in women with chronic WAD, Grades I–II, and chronic IONP. All measures pointed towards significantly increased segmental motions in the WAD group, suggesting that some patients with chronic whiplash may have increased segmental motion in the middle cervical spine segments. This may be an important predisposing factor for their chronicity. By trying out the new radiographic protocol on different patient groups, progress has been made towards establishing evidence-based criteria for abnormal sagittal plane segmental motions in the cervical spine.

■ Key Points

- A new measurement protocol was applied to precisely measure sagittal plane motion during flexion–extension in the lower cervical spine segments in women with chronic WAD, Grades I–II, and chronic IONP. A normal database for asymptomatic women served as a baseline.
- It is hypothesized that posteroanterior translational motion is a sensitive parameter for indicating abnormal segmental motion. This holds especially for the comparison between actually performed and predicted translation. This parameter and the actual rotational parameter identified significantly more women with increased segmental motion in the WAD group compared to the IONP group.
- A subgroup of women with chronic WAD, Grades I–II, has been identified that differs from women with chronic IONP. This subgroup might need a specific therapeutic intervention.

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