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The use of disharmonic motion curves in problems of the cervical spine

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Abstract Cervical spine motion was investigated by three-dimensional electrogoniometry in 257 asymptomatic volunteers and in 32 patients with cervical disc hernia or whiplash syndrome. Maximal ranges of main and coupled motions were considered. Motion curves were analysed qualitatively and using fitting of sixth degree polynomials. Motion ranges obtained were in agreement with previous observations. Significant differences between patients and volunteers concerned several primary and coupled components but not all. Qualitatively, patients displayed less harmonic curves, with irregularities and plateau-like appearances. Root mean square differences between data and fit were significantly modified in patients. Although cervical spine motion ranges may remain within normal limits in patients, motion patterns were altered qualitatively and quantitatively. Motion pattern analysis might prove a useful discrimination parameter in patients in whom anatomical lesions are not clearly identifiable.

Résumé Les mouvements cervicaux ont été étudiés par électrogoniométrie tridimensionnelle chez 257 volontaires asymptomatiques et chez 32 patients (hernie discale ou TAEC). Les amplitudes maximales des mouvements principaux et couplés ont été considérées. Les courbes de mouvement ont été analysées qualitativement et par ajustement polynomial du sixième ordre. Les amplitudes de mouvement étaient en accord avec les observations antérieures. Des différences significatives entre patients et volontaires concernaient plusieurs composantes principales et couplées, mais pas toutes. Qualitativement, les patients présentaient des courbes moins harmonieuses, avec des irrégularités et des apparences en plateau. Les écarts quadratiques moyens entre les données et l'ajustement étaient significativement modifiés chez les patients. Bien que les amplitudes de mouvement puissent rester dans les limites normales chez les patients, les schémas de mouvement étaient qualitativement et quantitativement altérés. L'analyse des schémas de mouvement pourrait s'avérer être un paramètre de discrimination utile chez les patients chez qui les lésions anatomiques ne sont pas clairement identifiables.

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Introduction

In cervical spine diseases, static (morphological) diagnostic investigations do not always provide useful information. Anatomical lesions are often difficult to identify in patients with the whiplash syndrome. Results of functional investigations provide evidence of hyper-mobility [5, 8, 9, 12, 25] and hypo-mobility [1, 5, 8, 9, 12, 14, 16, 17] in patients with disorders of the spine. However, van Mameren et al. [27] concluded that the total and the segmental range of motion are unsuitable as parameters of cervical spine mobility. The chronicity of the whiplash syndrome has been related to reduced cervical spine movement [10]. Asymmetry of sub-occipital left-right rotation ranges has been found in patients with soft tissue injuries of the upper cervical spine [3], and the increase in the neutral zone was found to be larger than the increase in range of motion in simulated instability [13, 22]. Other authors have even reported that motion ranges remain unaffected [24] or that motion velocity was altered [1, 26]. Moreover, alterations of motion patterns and/or associated movement components are liable to occur in patients with cervical problems [1, 23]. For instance, Dimnet et al. [5] and Lee et al. [18] showed alterations of cervical spine centres of rotation in patients with cervical disc disease. Similar findings concerning finite or instantaneous helical axes have been reported in patients with neck pain or injury [2, 21, 30, 31]. Alterations of motion patterns or course have been found in lumbar functional spinal units

[20]. Loudon et al. [19] reported a decreased accuracy in head position reproduction in whiplash patients. To the best of our knowledge, motion course in the cervical spine has not yet been studied.

The search for investigations that can establish a firm diagnosis of these problems still remains a challenge. Our study is an attempt to determine the possible contribution of motion patterns.

Materials and methods

Population

Between September 1994 and July 1998 cervical spine motion was analysed in 257 asymptomatic volunteers and in 32 patients. Informal consent was obtained from all those who took part in the study.

The asymptomatic volunteers were put into 3 age groups: there were 49 volunteers aged 14–19 years in the first group, 153 volunteers aged 20–29 years in the second group, and 55 who were aged 30–70 years in the third group. None of these volunteers had a history of present or past neck problems. They were selected at random from pupils attending a conventional secondary school, from students attending the University of Brussels, and from out-patients attending the Erasme University Hospital Orthopaedic Department with conditions not involving their spines.

Of the 32 patients tested, 12 suffered from cervical disc hernia, their average age was 51 years (range: 38–61 years), and they were tested before surgery (Cloward procedure). The remaining 20 patients had suffered a whiplash injury, their average age was 45 years (range: 24–71 years), and they were tested at an average of 5 months after injury (range: 1–22 months).

Global motion of the cervical spine was tracked using a 3-dimensional electrogoniometer (CA 6000 Spine Motion Analyser, O.S.I., Union City, CA). The device and set-up are described elsewhere [11], and it should be noted that the shoulders of the subjects were not immobilised.

Protocol

After registration of the reference position, 4 maximal active (maximal painless range) repetitions of each movement were realised. Motion velocity was not constrained. The sampling rate was set to 100 Hz, providing a good approximation of continuous motion tracking. The movements tested were flexion-extension, lateral bending and rotation. The parameters analysed were maximal ranges of primary and coupled motions (which are presented as the ratio of coupled motion to primary motion), a qualitative appreciation of motion pattern (harmony of motion path) as well as goodness of fit of 6th degree polynomials. For this analysis (Fig. 1) the initial and terminal “no motion” parts of the curve were first cut. Data was considered to represent “motion” (as opposed to “no motion”) if the absolute difference between primary motion sampled at instant t and instant t+0.1 s was equal or greater than 1 degree. Then a 6th order polynomial was fitted to the curve. The choice of this order of the polynomial was based on the results of tests with different orders (from 4th to 9th orders) on all curves of 10 asymptomatic volunteers. Quantitative analysis was performed by computing the root mean square (rms) difference between experimental points and the fit. Accuracy, precision and reproducibility evaluation have been described previously [11].

Statistical analysis

Normal distribution of all variables was verified using the Kolmogorov-Smirnoff test. Student’s “*t*” test for independent samples was used to compare average motion ranges and rms differences between the patient groups and the control group which consisted of the asymptomatic volunteers aged 30 and over. The same test was used to compare the three age groups of volunteers. Multivariate analysis of variance (MANOVA) and post-hoc LSD tests were carried out to assess the effect of age and pathology on the parameters analysed.

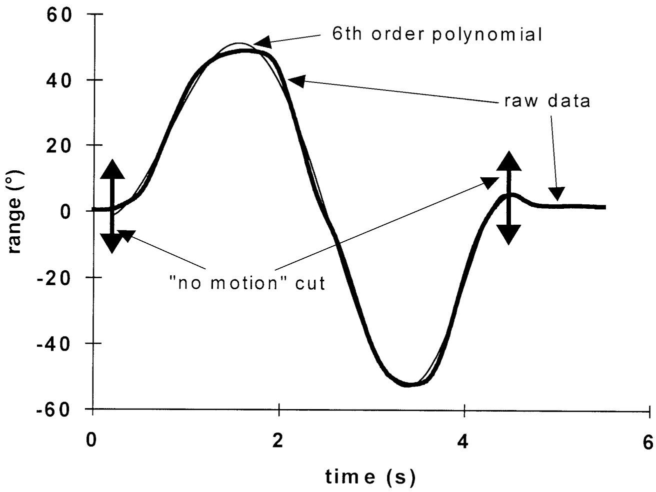

Fig. 1 Procedure of polynomial fitting

Results

Motion ranges

All primary motion ranges (Table 1) were significantly reduced in whiplash injury patients when compared to the control group (volunteers aged 30–70 years). In patients with cervical disc disease, sagittal and frontal plane motion ranges were significantly reduced. Some of the out-of-plane components were altered in both patient groups.

Motion curve patterns

Examples of motion course are given in Fig. 2a for asymptomatic volunteers and in Fig. 2b for patients. Qualitatively, volunteers displayed smooth, harmonic curves, whereas in patients the curves were not as harmonic and displayed irregularities (hesitations), plateaux around the maxima or an exponential shape. These alterations could not be linked to the type of pathology (whiplash injury or disc disease). Student “*t*” test carried out on the rms differences between experimental data and polynomial fit showed a significant difference in goodness of fit between volunteers and whiplash injury patients for cervical spine flexion-extension, lateral bending and rotation. These differences concerned primary and coupled motion curves. In the cervical disc group, the fit was significantly altered for a few motion components (Table 2). Except for rotation in flexed sagittal plane position, the primary motion rms difference between data and fit were not significantly altered in this patient group. Concerning coupled motion patterns, the coupled lateral bending component fit was always significantly modified.

Table 1 Mean cervical spine motion ranges and ratios (SD) in the control group and in both patient groups

	14–19 yrs (*n*=49)	20–29 yrs (*n*=153)	30–70 yrs[1] (*n*=55)	Whiplash (*n*=20)	Hernia (*n*=12)
Flexion-extension					
Flexion (°)	70 (10)	66 (10)*	57 (11)*	49 (15)**	51 (12)**
Extension (°)	61 (14)	57 (15)*	50 (15)*	40 (17)**	36 (11)**
Total (°)	131 (15)	123 (16)*	107 (16)*	89 (29)**	87 (21)**
Bending/flexion	–0.07 (0.09)	–0.05 (0.11)	–0.07 (0.09)*	–0.04 (0.11)	0.01 (0.09)**
Rotation/flexion	0.00 (0.09)	0.01 (0.10)	–0.02 (0.10)*	0.01 (0.11)	0.00 (0.09)
Bending/extension	0.03 (0.06)	0.04 (0.11)	0.00 (0.06)*	0.02 (0.13)	0.10 (0.06)**
Rotation/extension	–0.12 (0.11)	–0.07 (0.02)*	–0.07 (0.14)	–0.13 (0.14)	0.02 (0.08)**
Lateral bending					
Right bending (°)	48 (10)	45 (8)	39 (9)*	30 (9)**	34 (7)**
Left bending (°)	47 (9)	44 (7)*	38 (7)*	28 (10)**	32 (6)**
Total (°)	95 (16)	89 (14)*	77 (15)*	58 (17)**	66 (12)**
Flexion/right bending	–0.03 (0.24)	0.06 (0.21)*	0.14 (0.36)*	0.08 (0.36)	0.07 (0.20)
Rotation/right bending	0.53 (0.47)	0.36 (0.28)*	0.53 (0.36)*	0.47 (0.27)	0.32 (0.32)**
Flexion/left bending	0.32 (0.32)	0.16 (0.37)*	0.24 (0.26)*	–0.11 (0.35)**	–0.12 (0.23)**
Rotation/left bending	0.31 (0.40)	0.30 (0.46)	0.44 (0.35)*	0.33 (0.26)**	0.51 (0.34)
Rotation					
Right rotation (°)	75 (13)	71 (10)*	68 (11)*	53 (17)**	61 (14)**
Left rotation (°)	75 (12)	72 (9)	68 (13)*	49 (19)**	63 (11)**
Total (°)	150 (23)	143 (17)	136 (19)*	102 (35)**	124 (21)**
Flexion/right rotation	0.05 (0.21)	0.10 (0.17)	0.02 (0.16)*	0.08 (0.24)	0.06 (0.14)
Bending/right rotation	0.03 (0.27)	0.06 (0.17)	0.02 (0.13)*	0.02 (0.18)	0.07 (0.14)**
Flexion /left rotation	0.02 (0.12)	–0.01 (0.16)	–0.03 (0.09)	–0.03 (0.34)	–0.09 (0.13)**
Bending /left rotation	0.10 (0.20)	0.10 (0.16)	0.09 (0.17)	0.08 (0.18)	0.02 (0.13)**

* = Significant differences (Student's "*t*" test) to directly inferior age group, ** = Significant differences (Student's "*t*" test) of patients to control group (1)

Table 2 Student's "*t*" test (p: probability of equality) and MANOVA (effect of age and group) comparing patients root mean square differences between raw data and polynomial fit to those obtained in controls (55 subjects). H = hernia group (12 subjects), W = Whiplash group (20 subjects), Age = probability result of general MANOVA testing the effect of age on the root mean square differences, Group = probability result of general MANOVA testing the effect of grouping on the root mean square differences, § = significant difference (Student's "*t*" test) or significant effect (general MANOVA)

	Primary motion executed											
	Flexion-extension				Lateral bending				Rotation			
Motion component	H	W	Age	Group	H	W	Age	Group	H	W	Age	Group
Flexion	*0.19*	*0.01§*	*0.93*	*0.08*	0.01§	0.01§	0.50	0.01§	0.10	0.01§	0.79	0.02§
Bending	0.04§	0.02§	0.32	*0.11*	*0.39*	*0.04§*	*0.18*	*0.03§*	0.01§	0.01§	0.54	0.01§
Rotation	0.26	0.05§	0.35	0.26	0.23	0.24	0.67	0.15	*0.28*	*0.02*§	*0.50*	*0.02*§

MANOVA analysis (Table 2) showed that the differences in goodness of fit between the control group and both patient groups were not significantly affected by age. However, there was an effect of belonging to one of the pathological groups for primary and coupled motion patterns during lateral bending, and axial rotation, but not in flexion-extension. When considering asymptomatic volunteers, the effect of age on primary and conjunct motion course was significant for flexion-extension and lateral bending, but not for rotation. As compared to the control group, MANOVA tests showed a significant effect of grouping for all primary motion courses in the whiplash injury group, but not in the hernia group. Concerning coupled motion patterns, the group effect was significant during bending and rotation in both groups. However, the primary and coupled motion patterns of patient groups could not be distinguished from each other.

Discussion

In the present study, primary and coupled motion ranges of the cervical spine as well as parameters of motion course were sampled in a large population of asymptom-

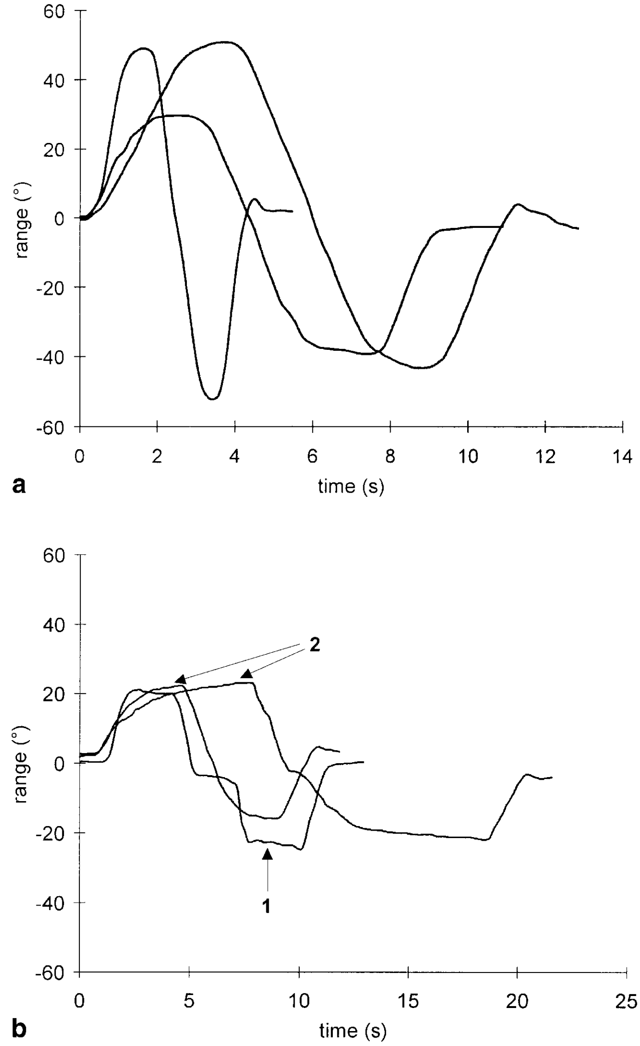

Fig. 2. a Flexion extension curves of asymptomatic volunteers. **b** Flexion extension curves of patients. Note the presence of various types of alteration – (*1*) plateau-like shape, (*2*) exponential shape

atic volunteers and in patients with whiplash injury or cervical disc hernia. In this first approach, motion course analysis was only based on simple polynomial fitting.

The CA 6000 was shown to be a reliable tool for measuring motion ranges of the cervical spine, confirming previous studies [4, 6, 15]. Thus it seemed acceptable to apply this instrument in clinical settings. The use of a high sampling frequency allows a reasonable approximation of continuous motion, enabling it to go beyond simple motion range analysis.

The functional alterations induced by disorders of the cervical spine are still not clearly established. Increased [5, 8, 9, 12, 25], decreased [1, 5, 8, 9, 12, 14, 16, 17], and unchanged [24] motion ranges, altered motion velocities [1, 26] or instantaneous centres or axes of rotation [2, 5, 8, 18, 21, 30, 31] have been reported in patients with problems of the cervical spine. These observations which seem conflicting might find an explanation in instability and stiffness phenomena and/or proprioceptive alterations [19] that might be related to these problems, but they also show that there is little agreement between physical examination and subjective pain and disability.

In the present study, all primary motion ranges were significantly reduced in both whiplash injury and cervical hernia patients. A decreased range of cervical spine motion was found to be present in patients with neck pain [1, 5, 14], disc [12], or spinal cord [17] disease and with cervical strain [16], whereas simulated disc lesions increase motion range [25]. Dimnet et al. [5] found a global decrease of cervical spine flexion-extension range in patients with neck pain. Segmental analysis showed that this decrease was localised in the lower portion of the cervical spine, while upper segments displayed hypermobility. According to Wiesner et al. [29], whiplash injury patients only sometimes display single segment hypomobility. Several studies have shown that motion ranges seem to be decreased only in moderate to severe pathologies of the spine, while earlier stages were more characterised by hypermobility [12]. The disc pathologies of the patients in the present study were all severe and required surgical treatment, so that our findings concerning this patient group are in agreement with the literature. Concerning the patients with whiplash injury, the delay between accident and functional test was variable. There was, however, no correlation between this delay and the cervical spine motion range.

Alterations of coupled motion ranges in patients with neck disorders have not yet been studied extensively. Alund et al. [1] reported alterations of motion patterns in steel workers with neck pain. Ogon et al. [20] observed an increase in coupled motion ranges in lumbar functional spinal units after simulation of various types of instability. In the present study, the whiplash injury group was only characterised by an inversion of the sagittal plane component during left lateral bending, which from flexion was changed into extension. The coupled axial rotation ratio during this motion was significantly reduced when compared to the control group, but it was close to that observed in younger groups. However, in patients with cervical disc herniation most coupled motion ratios were significantly altered, although a consistent trend could not be determined in these alterations.

This analysis of cervical spine primary and coupled motion ranges revealed in our patients with cervical disc herniation that primary and coupled motion components were altered, whereas in patients with whiplash injury they were only characterised by a reduction of primary motion ranges.

In recent years, several authors [2, 20, 21, 26, 28, 30, 31] have searched for parameters to analyse continuous motion of the spine, in an effort to go beyond simple motion range analysis. This approach has become feasible by the development of appropriate investigation tools. These studies have focused on instantaneous centres [28] or on axes of rotation [2], or on instantaneous helical axes [21, 30, 31] and on motion velocities and/or accelerations [1, 20, 26]. Ogon et al. [20] analysed hesitations or jerks of lumbar functional spinal units during motion. These were defined as discontinuous accelerations or decelerations, the location of which was determined with respect to primary motion. The approach chosen in the present study was aimed at completing the parameters mentioned above and consisted in statistal analysis of simple polynomial fitting. Qualitatively, the motion curves obtained in asymptomatic volunteers were smooth, harmonic and continuous (Fig. 2a). However, several types of alteration were observed in the patient groups. Motion curves displayed hesitations (which could be related to slower motions observed in patients), similar to the ones obtained by Ogon et al. [20], exponential shapes, and/or a plateau-like shape around the maximum of primary motion (Fig. 2b). These alterations concerned primary and coupled motion curves. Hesitations might be related to various parameters, such as pain, propriocepive alterations, and/or alteration of muscle coordination. The rms difference between raw data and the polynomial fit was significantly altered in patients with whiplash injury as compared to the control group, demonstrating that motion course was significantly altered in these patients. In the cervical disc hernia group, coupled lateral bending course was significantly modified during lateral bending and rotation. In this group, primary motion course did not display significant alterations.

The results of the present study provide information in favour of functional parameters of the cervical spine, such as primary and coupled motion ranges and harmony of motion course. These parameters might be worth investigating in cervical spine patients in whom classical investigations fail to reveal anatomical lesions, or in whom the lesions are not clearly identified.

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