Int J Legal Med (2003) 117 : 350–355
DOI 10.1007/s00414-003-0402-7

ORIGINAL ARTICLE

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The effects of protocol and test situation on maximal vs. submaximal cervical motion: medicolegal implications

Received: 23 May 2003 / Accepted: 11 September 2003 / Published online: 22 October 2003

Abstract The objectives of this study were to examine the influence of the measurement protocol on the range and consistency of cervical motion (CM) in maximal vs. feigned limitation of CM, to explore some cognitive aspects of the feigning performance and to assess the effect of imagined pain vs. financial gain as a stimulus for the submaximal performance. The directions of flexion, extension, right and left rotation and right and left lateral flexion were measured in 26 normal subjects. Four protocols were compared: performance of CM with eyes open vs. eyes closed and testing at either a repetitive (within direction) or random (among directions) order. In each direction three measurements were recorded. Subjects were initially asked to move the head maximally, they were then presented with a vignette describing a fictitious accident involving the neck and were told to feign CM limitation in order to achieve unlawful compensation. In the third part, subjects were instructed to limit CM due to an imagined severe pain applying the repetitive order-eyes open paradigm only. Maximal CM paradigms were associated with significantly larger range (p=0.0000) and higher consistency (p=0.0000) compared the feigning paradigms. The eyes open-repetitive order protocol best separated between maximal and feigned performance. It was also indicated that the majority of subjects used the sensation of tension in the neck region as a cue for feigning while attempting to be as consistent as possible. Compared to feigning motivated by financial gain, limitation due to imagined pain resulted in significantly greater CM reductions and lesser consistency. The findings suggest that while feigning of motion impairment is probably based on somato-sensory input, the preferred CM testing protocol should consist of within direction repetitive movements with eyes open.

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Keywords Cervical spine · Motion · Protocol · Effort · Feigning

Introduction

Limitation of active cervical motion (CM) is a major symptom among patients suffering from whiplash-associated disorders (WAD) and is also a principal criterion for the determination of cervical impairment [1, 2, 3, 4]. However, since active CM requires that the patient performs at the maximal level (also known as maximal effort, ME) confirmation of ME is critical to the determination of the severity of impairment. Without such confirmation, the findings derived from the test are clinically meaningless [5]. It follows that the availability of a standard CM measurement protocol which is also capable of effort verification, is singularly important in the medicolegal field where clinicians often suspect non-collaboration among WAD patients presenting with no positive neurological, radiological or orthopedic findings. This patient group constitutes the majority of the caseload and exerts an outstanding impact on health and economical resources [6].

Improvements in CM measurement and interpretation may be brought about by using more accurate measurement systems and the adoption of protocols which are associated with a higher degree of reproducibility. The last decade saw a significant breakthrough in accuracy with the introduction of dedicated 3D motion analysis systems characterized by high resolution which record, calculate and display spatial head positions [7, 8, 9]. Using such a system enabled the comparison of CM test protocols consisting of either consecutive or random repetitions of movements [10]. It was indicated that repetitive performance of the same movement resulted in a slightly larger CM and better consistency compared to that derived from its random counterpart.

Regarding the sensitivity and specificity of CM measurements, a recent study demonstrated that the coefficient of variation (CV) could very effectively separate maximal from feigned limitation of CM in normal subjects [11].

However methodological factors such as the order of testing, the availability of visual cues or the nature of instructions according to which subjects feigned performance had not been explored.

In view of the previous studies it was hypothesized that by confounding the CM measurement protocol by obliterating visual cues and using random order of movements, the likelihood of identifying submaximal performers would be further improved. The first objective of the present study was therefore to examine in more detail the effects of repetitive vs. random order of movements as well as eyes status (open vs. closed) on maximal and feigned limitation of CM in order to recommend an optimal protocol for medicolegal evaluation of CM impairment. The second objective was to assess the effect of different methods used for intentionally reducing the range of CM.

Materials and methods

Subjects

A total of 26 healthy individuals, 21 women and 5 men aged 21–52 years, were randomly recruited out of a group of 55 prospective subjects comprising the staff and students of the Master's program at the Department of Physical Therapy, Sackler Faculty of Medicine, Tel Aviv University. None of the subjects had any history of cervical spine problems. In keeping with the requirements of the University's Institutional Review Board, all subjects signed an informed consent form.

Instrumentation

Measurement of cervical motion was performed using the Zebris CMS 70P system (Zebris Medizintechnik, Isny, Germany). The principle of operation is based on the determination of the spatial coordinates of miniature ultrasound (US) transmitters whose position relative to a fixed system of three microphones is derived from the time delay between the US pulses, using triangulation [8]. The transmitters are arranged in two triplets which are attached to the head and chest frames, respectively. The spatial position of the head is calculated by a dedicated software and graphically displayed in real time.

Measurement procedure

Measurements took place during daytime in a quiet room. Subjects sat on an ordinary chair with firm seat and backrest, positioned at a distance of about 1 m from the microphones. Subjects were asked to assume a relaxed posture with the feet located parallel on the ground and hands resting freely on the thighs. With the attachments in place, the zero (reference) position was defined as the anatomical position of the head (vertically upright without rotation), subjectively determined by each subject. Three sets of measurements were performed with a break of 30 min. between them.

In the first part of the initial set of measurements subjects were asked to maximally move the head along each of the primary directions: flexion, extension, right and left rotation and right and left lateral flexion [10]. In the first protocol designated as RepOM (*Rep* repetitive, *O* eyes open, *M* maximal), the subject's eyes were open and the head was moved from the initial neutral position, toward maximal range in a given primary direction (e.g. left lateral flexion), back to the neutral position and then maximal motion to the opposite (i.e. right lateral flexion) and return to neutral position. Subjects were instructed to perform at a comfortable, self-selected pace. This sequence was repeated 3 consecutive times with 3 s pause between each pair. The order of planes was sagittal, transverse and frontal and there was a 10 s pause before progressing to the next plane. The mean value of each triad of movements was considered the representative score. A break of 5 min followed before commencement of the second protocol (RanOM) which differed from the previous protocol by randomly assigning an individual primary direction and performing a single motion (e.g. neutral – extension – neutral). For instance a single sequence would consist of extension, *R* lateral flexion, *R* rotation, *L* lateral flexion, flexion and *L* rotation. This sequence was repeated 3 times with 3 s pause between movement at each primary direction and a 10 s pause between sequences.

In the second part of the first set which followed 15 min later, subjects were asked to feign limitation of CM. During the break the examiner read to the subject the following paragraph: "Imagine that 2 years ago, you were involved in a motor vehicle accident. As a result you have suffered various symptoms affecting your cervical spine. Today, although symptom-free, you claim damages for a non-existing cervical impairment. In the next set of measurements, try to convince me that your claim is well-founded and that you still suffer from those symptoms." This protocol was termed RepOF and was accordingly followed by its random counterpart, RanOF. Following a 15 min break the second set was identical to the first set except for eyes status which were now closed (marked as *C*). The corresponding protocols were designated as RepCM, RanCM, RepCF and RanCF.

Following completion of the second set subjects were asked to fill in a questionnaire consisting of the following questions:

1. Have you actually planned the feigning?
2. Have you tried to reproduce in the most consistent manner each of the three repetitive movements?
3. Have you tried to perform differently in each of the three repetitive movements?
4. While feigning, which cues have you used?
5. Was feigning more difficult during the random protocols?
6. Was feigning more difficult when conducted with eyes closed?
7. Have you changed your feigning strategy during performance of the tests?

In the third part, subjects were asked to imagine they were suffering from intense cervical pain and instructed to perform the test in a repetitive order with eyes open only. This protocol was designated as RepOP and conducted 30 min after completion of the second set.

Statistical analysis

Descriptive and inferential statistics (ANOVA with repeated measurements) using the BMDP statistical software (BMDP Statistical Software Inc., Los Angeles, CA). The coefficient of variation (CV=[SD/mean]*100) was used as the parameter of consistency [11, 12].

Results

ME vs. feigned effort (FE) protocols

Table 1 outlines the mean and SD obtained for each of the maximal and feigned protocols respectively in terms of the primary directions. As evident from this table the CM during FE protocols was reduced by a margin of 45–69% (mean 56%) relative to the corresponding primary directions in the ME protocols (p=0.0000). Notably there was a clear tendency in all directions, for the reductions to increase with the apparent complexity of the protocol. For instance, in extension, RepOF was reduced by 55.5% compared to RepOM, RepCF by 62.9% compared to RepCM,

Table 1 Range of motion in maximal and feigned effort (in º) according to protocol

Protocol	Flexion	Extension	Right rotation	Left rotation	R. lat. rotation	L. lat rotation
RepOM	59.2 (13.9)[a]	61.9 (16.5)	74.4 (7.9)	72.2 (12.6)	44.6 (7.8)	44.4 (8.7)
RepCM	58.8 (14.1)	62.7 (17.5)	73.3 (10.4)	73.7 (12.6)	43.5 (9.2)	45.3 (9.2)
RanOM	59.3 (13.6)	63.1 (16.6)	73.2 (8.6)	69.1 (9.6)	42.8 (8.2)	45.6 (9.2)
RanCM	56.3 (14.9)	63.8 (14.6)	71.1 (8.5)	67.8 (11.1)	41.5 (8.9)	44.6 (8.9)
RepOF	25.5 (10.6) 56.9%[b]	27.5 (13.0) 55.5%	36.1 (11.6) 51.4%	37.7 (14.3) 47.7%	24.0 (7.0) 46.1%	24.1 (8.8) 45.7%
RepCF	24.8 (12.8) 57.8%	23.2 (14.5) 62.9%	32.7 (12.6) 55.3%	33.3 (18.3) 54.8%	21.3 (7.9) 51.0%	23.6 (7.9) 47.9%
RanOF	20.7 (11.1) 65.1%	22.3 (11.5) 64.6%	32.8 (12.4) 55.2%	30.6 (12.0) 55.7%	20.7 (7.6) 51.6%	21.4 (6.1) 53.0%
RanCF	19.6 (9.7) 65.2%	19.5 (11.0) 69.4%	28.2 (10.0) 60.3%	27.9 (13.4) 58.8%	18.8 (7.8) 54.6%	19.2 (8.2) 56.9%

Rep repetitive order, *Ran* random order, *O* eyes open, *C* eyes closed, *M* maximal, *F* feigned.
[a]Mean(SD).
[b]Percentage reduction in the feigned effort protocol relative to the corresponding maximal effort protocol.

Table 2 Coefficient of variation in maximal and feigned effort (in %) according to protocol

Protocol	Flexion	Extension	Right rotation	Left rotation	R. lat. rotation	L. lat rotation
RepOM	3.3 (2.6)[a]	3.5 (3.2)	2.0 (1.4)	2.1 (1.5)	2.9 (2.1)	3.7 (3.0)
RepCM	4.6 (5.3)	4.0 (5.3)	2.5 (2.0)	2.6 (2.2)	3.5 (2.7)	2.9 (2.1)
RanOM	3.7 (3.3)	3.7 (6.0)	3.2 (2.3)	2.9 (1.7)	4.8 (3.4)	4.7 (2.7)
RanCM	6.5 (7.3)	3.5 (2.3)	3.3 (2.5)	5.3 (6.6)	6.9 (8.3)	4.3 (2.9)
RepOF	14.8 (12.6) 4.48[b]	15.6 (18.5) 4.45	13.6 (8.9) 6.80	10.7 (7.7) 5.09	11.3 (8.4) 3.89	13.2 (9.0) 3.56
RepCF	15.2 (14.6) 3.30	18.8 (15.8) 4.70	11.2 (7.1) 4.48	14.7 (16.3) 5.65	13.6 (9.9) 2.57	11.0 (6.1) 3.79
RanOF	20.8 (19.6) 5.62	17.3 (11.7) 4.67	13.6 (11.0) 4.25	13.8 (13.4) 4.75	11.9 (9.8) 2.47	13.6 (10.2) 2.89
RanCF	17.6 (14.1) 2.70	14.2 (11.7) 4.05	16.1 (12.4) 4.87	18.6 (22.4) 3.50	14.3 (9.4) 2.07	15.2 (9.7) 3.53

Rep repetitive order, *Ran* random order, *O* eyes open, *C* eyes closed, *M* maximal, *F* feigned.
[a]Mean(SD).
[b]The ratio of the average CV in the feigned effort relative to corresponding average CV in the maximal effort protocol. For instance CV in RepOF is 14.8% and in Rep-OM 3.3%, thus the ratio CVm/CVf is 4.48.

RanOF by 64.6% compared to RanOM, and RanCF by 69.4% compared to RanCM. Table 2 compares the corresponding CVs and as expected there was a drastic increase in the dispersion of the scores reflected by a significantly higher CV (p=0.0000). In terms of the average CV this increase ranged between 2.07-fold and 6.80-fold.

To render the findings more compact and clinically interpretable, the ranges of motion associated with all six directions within the same protocol were added arithmetically. This resulted in protocol-specific total CM and CV scores. The findings are presented in Fig. 1 and Table 3 and reveal the drastic reduction in CM while attempting to feign limitation. This reduction reflected the complexity of the task namely the highest score was achieved in RepOF and the lowest in RanCF (Fig. 1). An inverse trend was apparent with respect to the consistency which took the same shape albeit in a different magnitude for both the ME and FE protocols. Notably, the consistency of performance deteriorated as a function of the test complexity in the following order: RepO, RepC, RanO and RanC, respectively. Based on these scores interprotocol comparisons were performed indicating that all possible combinations between maximal and feigned effort protocols yielded highly significant differences (p=0.0000). Moreover, findings based on protocol RanCM were significantly different from those derived from the other three maximal effort protocols both in terms of the range of motion and the consistency. This result indicates that performing with eyes closed and in a non-repetitive order results is a particularly exacting task even when performed at the maximal level of effort.

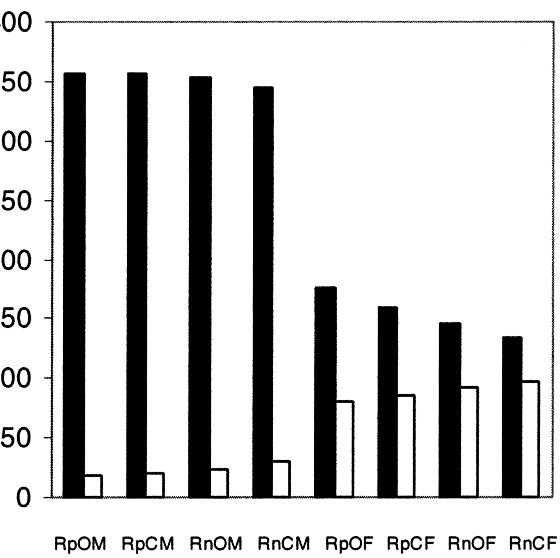

Fig. 1 Variation of the total CM (*solid columns*) and total CV (*hollow columns*) as a function of the test protocol. X-axis: type of protocol, Y-axis: numbers correspond to (º) for CM and (%) for CV. (*Rp* repetitive, *Rn* random, *O* eyes open, *C* eyes closed, *M* maximal, *F* feigned)

To find out which among the four combinations, RepO, RepC, RanO and RanC led to the smallest number of

Table 3 Total CM (in º) and the corresponding CV (in %) scores for each protocol: mean (SD)

Protocol	Total CM (º)	Total CV (%)	CV range (%)
RepOM	356.7	17.8 (7.0)[a]	6.8–31.9
RepCM	357.3	20.4 (11.4)	7.0–57.4
RanOM	353.1	23.3 (12.4)	10.0–67.8
RanCM	345.1	30.0 (18.3)	12.2–95.0
RepOF	174.9	79.6 (33.0)	32.1–167.1
RepCF	158.9	84.8 (36.3)	27.4–175.3
RanOF	148.5	91.1 (34.2)	28.8–147.7
RanCF	133.2	96.4 (50.3)	27.2–234.1

CV-based false negative cases, the individual CV scores of all subjects were aligned in such a way that repetitive and random ME protocols could be compared with the corresponding FE protocols. Scanning of the individual CV scores revealed that in none of the subjects was there a single case where the CV derived from the maximal performance exceeded the corresponding individual score in feigned limitation. Thus even on an individual level feigning was invariably and profoundly less consistent.

However, since the best consistency in maximal performance was obtained in RepOM protocol (lowest individual CV=6.8%, highest individual CV=31.9%, not in the same subject) the upper limit (31.9%) was compared with the lowest individual CV in any of the feigned effort protocols. As the lowest CV score in protocol RepOF was 32.1%, performing head motion according to the RepOM protocol resulted in total separation between the parallel ME and FE protocols. Comparison with RepCF, RanOF and RanCF yielded 1, 2 and 2 false negative cases, respectively. Other comparisons yielded decisively less conclusive results. For instance, pairing RanOM with RanOF, RanCF, RepOF and RepCF resulted in 8, 9, 12 and 12 false negative cases, respectively.

Results of the questionnaire

The main findings of the questionnaire are:

a. More than 50% of the subjects planned the feigned performance
b. All subjects save one tried to be as consistent as possible
c. Sensation of tension or pressure during motion of the neck served as the most frequent cue (76%) for positioning of the head in less than the most distant location followed by visual (15%) cues in the eyes open protocols
d. Random protocols proved to be either equal (27%) or more challenging (54%) than their repetitive counterparts
e. Feigning with eyes open proved to be either equal (27%) or easier (54%) to perform than with eyes closed.

Table 4 Imagined pain-based CM and CV

Direction	Mean (SD) range of motion (in º)	Mean (SD) of the CV (in %)	Reduction compared to RepOF (in %)
Flexion	17.2 (14.8)	20.7 (15.5)	32.6
Extension	17.3 (13.0)	19.6 (13.8)	36.9
R. rotation	21.3 (13.5)	23.2 (18.7)	40.9
L. rotation	21.8 (14.3)	15.2 (10.9)	42.3
R. lat. rotation	16.5 (7.7)	14.4 (10.3)	31.5
L. lat. rotation	16.6 (10.4)	14.6 (9.7)	31.0

Imagined pain-based submaximal performance

Table 4 outlines the CM findings as well as associated CVs derived from this protocol. Statistical analysis revealed highly significant differences in the CM between these findings and those derived from all eight conditions: 2 ('order') ×2 ('eyes') ×2 ('effort level') with the least significant difference indicated with respect to RanCF: $F_{1,23}=4.80$, $p=0.038$. The opposite trend characterized the CV analysis which pointed out to a significant increase in this parameter. Among the eight individual protocol comparisons, in three cases no difference was indicated: RepCF, RanOF, RanCF.

Discussion

This study focused on some aspects of CM testing that are pertinent to the conduction of a valid measurement, particularly in the medicolegal context. Based on a model that compared the sensitivity of differentiating FE from ME, the principal finding of the study is that measurement should proceed in an orderly fashion from one direction to the other using consecutive repetitions with the subject's eyes open**.** The other findings relate to the significance of pain as a cue and the role of planning in submaximizing CM performance.

One of the leading sources regarding protocols for joint motion measurement is the American Medical Association's guides for evaluation of permanent impairment [13]. In the context of evaluating CM the recommended approach is based on performing three reciprocal repetitions in each motion direction and in the following order: flexion then extension, rotation to the right then to the left and lateral flexion to the right followed by the same motion to the opposite side. No explicit reference is made to the visual status. Most important, for verifying full patient collaboration (namely ME) a maximal difference of 5º from the average score of the three repetitions for motions that are less than 50º and a maximal difference of 10% otherwise serve as the criteria. However, these medicolegal criteria have been seriously challenged in view of their very poor differentiation capacity between ME and SE [11]. The failure of these criteria to indicate submaximal effort may well reflect the accuracy of the proprioceptive mechanism which, as revealed in the present study, serve among most subjects for head positioning in the simulation paradigms.

With respect to the effect of visual status, previous empirical observations and comments made by subjects/patients have indicated that by focusing the eyes on special objects located within the range of head motion, could potentially assist in maintaining both good consistency and smaller range of motion. Indeed, as revealed by the questionnaire, 15% of the subjects in the present study claimed to have used visual cues for positioning the head in the feigning paradigms. Examination of the four combinations of eyes open vs. eyes closed indicates that except for the case of RepOM-RepCM, blocking of visual contact resulted in smaller CMs. Moreover, in all of the above combinations the CV of the combined CM score was consistently higher in the closed compared to the open situation.

The introduction of randomized measurement order was based on our previous research which indicated that it affected CM [10] although to a limited extent (on average about 3º). However, the effect of this parameter has not been studied with respect to feigning of CM. As demonstrated in the present study, in all four combinations of repetitive vs. random paradigms, the former resulted in larger CMs compared with the latter. The opposite trend occurred with respect to the CV. It was thus hypothesized that confounding the protocol by randomly ordered movements of the head that were coupled with blocking of visual information, would render consistent performance more difficult, leading to even higher CVs and a better differentiation capacity.

However, as revealed by introduction of the FE as an independent parameter, this was not the case since despite its associated large CVs, protocol RanCF did not operate effectively. It is suggested that the reason for this failure is the difficulty in maintaining consistent motor patterns experienced by subjects performing maximally (under protocol RanCM). This had resulted in particularly large CVs in flexion and rotations leading to a relatively smaller increase in the corresponding RanCF-based CV scores. Hence the ‘gain’, achieved by presenting the subject with a more complicated motor task, reflected by much larger CVs in the RanCF, was more than offset by a parallel increase in RanCM.

On the other hand, although associated with fairly low CVs, the repetitive-eyes open protocols (in ME and FE) were characterized by total separation, meeting fully the requirement for sensitivity. Clearly, this statement may be qualified by the suitability of test protocols based on normal subjects to patients presenting with a variety of pathologies. It should however be borne in mind that the vast majority of clinical performance tests are based on standardization in normal populations. But even more relevant to the present issue is the observation that individuals who fraudulently claim to suffer from CM limitation should be regarded as normal subjects. On the other hand this protocol is not likely to compromise patients who genuinely present with motion CM impairment and therefore the RepOM protocol is suggested as a standard testing procedure.

As revealed by this study the nature of the instructions, concerning the simulated effort, has a decisive effect on performance. Although tested with respect to the sagittal plane only, simulation under pain results in profoundly sharper CM limitation than compared to simulation under financial gain. In an as yet unpublished study, CM measurements were performed in a group of patients suffering from chronic grade II WAD [13] who were candidates for invasive treatment. In a later part of the measurement session they were asked to move their head as if suffering from a very intense pain. The findings indicated a reduction of CM and rise in the CV, the latter increasing on average by about 3% from 8–10%. In the present study, the average scores of the CVs (based on the CVs of all directions within an individual paradigm) were 2.9, 13.2 and 18.0% in RepOM, RepOF and RepOP, respectively. Thus the importance of the average (SD) of the CV in RepOP is in delineating a realistic cut-off score for a positive determination of submaximal performance.

Although the percentage of unsubstantiated WAD-related claims cannot be determined with certainty, studies point out that a substantial number of cases do not have sufficient clinical ground. For instance, normal subjects were exposed to a simulated rear-end collision which in fact did not result in an acceleration-deceleration of the head, thought to be the primary cause for the whiplash injury. Yet 17% of the subjects reported symptoms that were typical for whiplash [14]. An epidemiological study has revealed that a change from a tort to a no-fault system in the province of Saskatchewan resulted in a substantial decrease in direct health care costs [15]. In spite of the controversy associated with this study it is quite obvious that the serious dearth of symptom validation mechanisms render well founded clinical decisions regarding some of the main WAD very difficult.

With respect to limitation of CM, the use of the RepO protocol together with CV-based cut-off scores (TD) improves the clinical decision making process. However, a number of medical and legal qualifiers must be borne in mind. First, since CM limitation may be due to pain and as the latter could be provoked in a non-consistent fashion, a large overall CV should not lead to immediate patient disqualification but further testing is required. Second, a decision regarding a minimum number of directions (out of the six available) in which the CV score is extreme and therefore indicating submaximal performance, is necessary. Third, the use of a cut-off score requires the setting up of confidence limits: 90%, 95% or 99% [11]. Which of these should serve as the accepted legal benchmark has never been established.

In conclusion, the present study recommends the use of repetitive order-eyes open CM test protocol for assessing the cooperation of patient with neck-related disorders.

References

1. Osterbauer P, Long K, Ribaudo T (1996) Three dimensional head kinematics and cervical range of motion in the diagnosis of patients with neck trauma. J Manipulative Physiol Ther 19: 231–237

2. Dall'Alba PT, Sterling MM, Treleaven JM, Edwards SL, Jull GA (2001) Cervical range of motion discriminates between asymptomatic persons and those with whiplash. Spine 26:2090–2094
3. Kasch H, Bach FW, Jensen TS (2001) Handicap after acute whiplash injury. A one year prospective study of risk factors. Neurology 56:1637–1643
4. Kasch H, Stengaard-Pedersen K, Arendt-Nielsen L, Jensen TS (2001) Headache, neck pain and neck mobility after acute whiplash injury: a prospective study. Spine 26:1246–1251
5. Polatin PB, Mayer TG (1992) Quantification of function in low back pain. In: Turk DC, Melzack R (eds) Handbook of pain assessment. Guilford Press, New York, pp 32–48
6. Haines F (1999) Automobile insurance – trends in the neck soft-tissue injury claims. In: Proceedings of the First World Congress on Whiplash Associated Disorders, Vancouver, pp 90
7. Dvořak J, Antinnes JA, Panjabi M, Loustalot D, Benomo M (1992) Age and gender related normal motion of the cervical spine. Spine 17:S393–398
8. Dvir Z, Prushansky T (2000) Reproducibility and instrument validity of a new ultrasonography-based system for measuring cervical spine kinematics. Clin Biomech 15:648–654
9. Trott PH, Pearcy MJ, Ruston SA, Fulton I, Brien C (1996) Three dimensional analysis of active cervical motion: the effect of age and gender. Clin Biomech 11:201–206
10. Dvir Z, Werner V, Peretz C (2002) The effect of measurement order on cervical range of motion scores. Physiother Res Int 7:136–145
11. Dvir Z, Prushansky T, Peretz C (2001) Maximal vs. feigned active cervical motion in healthy subjects: the coefficient of variation as an indicator of sincerity of effort. Spine 26:1680–1688
12. Doege TC, Houston TP (1993) Guides to the evaluation of permanent impairment, 4th edn. American Medical Association, Chicago, pp 116–122
13. Dvir Z, Gal Eshel N, Pevzner Y (2004) The effect of simulated pain in cervical motion and its consistency in patients suffering from whiplash associated disorders. Clin J Pain (submitted)
14. Castro WH, Meyer SJ, Becke ME et al. (2001) No stress–no whiplash? Prevalence of whiplash symptoms following exposure to a placebo rear end collision. Int J Legal Med 114:316–322
15. Cassidy JD, Carroll L, Côte P, Lemstra M, Berglund A, Nygren A (2000) Effects of eliminating pain and suffering on the incidence and prognosis of whiplash claims. N Engl J Med 342:1179–1186