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ORIGINAL ARTICLE

Three-dimensional analysis of cervical spine motion: reliability of a computer assisted magnetic tracking device compared to inclinometer

Ioannis D. Gelalis · Louis E. DeFrate · Kosmas S. Stafilas · Emilios E. Pakos · James D. Kang · Lars G. Gilbertson

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Abstract We aimed to investigate the reliability and reproducibility of a magnetic tracking technique for the assessment of overall cervical spine motion (principal and coupled movements). Ten asymptomatic male volunteers with a mean age of 29.3 years (range 20–37 years) were included in the study. Flexion, extension, left and right lateral bending and left and right axial rotation were measured using a magnetic tracking device (MTD) mounted onto a custom head-piece. For rotational movements in the frontal and sagittal planes the results were compared with the measurements of two standard inclinometers. Intra-observer, inter-observer and intra-instrument reliability was assessed with the intraclass correlation coefficient method. There were no significant differences for all motion measurements between the MTD and the inclinometer. High inter-observer reliability was found in flexion, extension, axial rotation and lateral bending indicating that the testing routine is applicable for different examiners. The intra-observer variability was high in flexion and extension, whereas in lateral bending the reliability coefficients were lower and displayed a fair to good reliability for most of the measurements with the MTD. The results of the MTD were found to be highly comparable with the inclinometer results with an inter-instrument correlation coefficient ranging from 0.88 to 0.99. The MTD is a reliable, reproducible method for three-dimensional motion analysis of the cervical spine and therefore a valuable method both for the clinical assessment of various degenerative and traumatic disorders and as a supplement of different therapeutic procedures and rehabilitation.

Keywords Three-dimensional motion analysis · Kinematics · Cervical spine · Electromagnetic tracking device · Inclinometer

I. D. Gelalis (✉) · K. S. Stafilas · E. E. Pakos
Department of Orthopaedic Surgery,
University Hospital of Ioannina, School of Medicine,
University of Ioannina, 45100 Ioannina, Greece
e-mail: idgelalis@msn.com

L. E. DeFrate · J. D. Kang · L. G. Gilbertson
Musculoskeletal Research Center,
Department of Orthopaedic Surgery,
University of Pittsburgh Medical Center, Pittsburgh, PA, USA

Introduction

Injuries and various degenerative conditions of the cervical spine are frequently associated with pain and limitation of mobility. Accurate methods for measuring cervical spine motion are therefore of great significance for baseline information and evaluating clinical outcomes. Apart from insight in the total mobility, the range of motion can also be used to observe any intra- or inter-subject differences, which are important in the assessment of therapeutic interventions. Many studies have reported on cervical spine motion assessment using different techniques, such as radiography, electrogoniography, optical and ultrasonic techniques, and have proposed variable norms of cervical range of motion, reflecting the difficulty of accurate measurement. Yet, there is no gold standard for the measurement of spinal range of motion [3, 11, 19].

Several radiographic techniques, such as conventional radiography, cine-radiography and stereoradiography, have been reported to be accurate and objective methods for the evaluation of the cervical range of motion [8, 15, 18]. Functional computed tomographic scans were also used to measure segmental rotation in the cervical spine [13, 14, 26]. However, the radiographic techniques have the disadvantage of radiation exposure, equipment availability, expense and time consumption. Moreover, goniometric techniques have been employed to measure cervical range of motion with high reproducible measurements and good correlation with radiographically determined range of motion [1, 12, 20, 23, 27, 28]. Several studies have compared different methods for the evaluation of cervical range of motion and investigation of their reliability [25, 27, 29]. Others have underlined the need for more accurate methods to measure the complexity of cervical spine motion [8, 15, 16].

The "Flock of Birds" system, is a non-invasive electromagnetic tracking device (MTD) that has been used for three-dimensional analysis of overall spine motion with encouraging results in respect to accuracy in cervical spine [4–7, 21]. The accuracy and reliability of this measurement technique was evaluated for measuring the cervical ROM at the Center for Rehabilitation of the University Hospital Groningen, Netherlands. The reproducibility of axial rotation, forward flexion and lateral bending was within 0.85° and was within 1.7° for combined movements such as axial rotation in flexed or extended position [17]. The aim of this study was to establish the inter- or intra-observer reliability of the "Flock of Birds" system in the assessment of cervical range of motion and to assess the inter-instrument reliability compared to a standard inclinometer.

Materials and methods

Ten asymptomatic male volunteers, with normal physical status and no previous history of cervical spine surgery, cervical spine trauma or cervical pain, were included in this study. The mean age of the volunteers was 29.3 years (range 20–37 years). All volunteers were engaged in sedentary and routine activities of daily living. An informed consent was obtained from all of them. Kinematic measurements were made using the electromagnetic tracking device "Flock of Birds™" (Ascension technology Corporation, Burlington, USA). This device is a six degrees-of-freedom measuring device consisting of a transmitter that creates a pulsed direct current (DC) electromagnetic field that is simultaneously measured by one or multiple receivers. From the measured electromagnetic field characteristics, each receiver independently computes its position and orientation. The overall rotational data are displayed in real time on a personal computer. The technical specifications of this device include a positional range of 122 cm, angular range of 180°, static positional accuracy of 0.25 cm root mean squared (RMS) and static angular accuracy of 0.5° RMS. An MRI compatible halo ring (Bremer Medical Inc., Acromed Co. Acksonville, FL, USA), composed of aluminium–magnesium alloy and modified by attachment of eight positioning pads was used as a head mount for one sensor. A second receiver was attached on the chair's backrest.

All subjects were seated in a wooden chair, and their shoulders were restrained with straps so that their torso maintained contact with the chair's backrest. Their arms rested freely on their sides and their feet were positioned flat on the floor. The head-piece was placed on each subject's head, 1 cm above the ear tips and stabilized in this position by tightening the positioning pads. The positioning pads provide stabilization of the head-piece and reduced random movements of the head-piece due to subject's hair and scalp. The transmitter was positioned a distance of 10 cm behind the receiver attached to the chair (Fig. 1).

Subjects were examined in a relaxed sitting position in a chair with armrests, facing a mirror placed at a standard distance opposite to them and were initially instructed to sight on a single point at their reflection in the mirror, defining their neutral head-neck position. Before each measurement the subjects were reminded about the importance of a neutral head-neck position and were asked to assume a neutral head-neck position by looking at their reflection in the mirror. The range of motion maneuvers were obtained by asking the subjects to move their head maximally in the following rotational degrees-of-freedom: flexion, extension, right lateral bending, left lateral bending, right axial rotation, and left axial rotation. Each subject was instructed to minimise the coupled motions and to

Fig. 1 The "Flock of Birds" system

return to his neutral position after each maneuver and was encouraged to perform maximum excursion for each maneuver without excessive effort. The velocity of the maneuver was at a gradual, normal speed. During each maneuver the examiner observed the real time data displayed on the computer screen to ensure the quality of the test.

Reliability was tested by examining each subject two times subsequently by two investigators who performed the measurements independently on subsequent days, at the same time of day. There was no contact between the investigators, between measurements or during the entire study period. The subjects were instructed not to comment on the measurement of one investigator to the other. The sequence of the investigators was determined randomly using a computer-generated sequence table.

The subject's active range of motion was recorded by each observer two times in each of the six degrees-of-freedom. For comparison, flexion-extension and lateral bending measurements were performed simultaneously with two standard inclinometers, which were attached on the head-piece in the frontal and sagittal plane. The values were measured and reported as the average value of the three trials.

An intra-class correlation coefficient (ICC), one way random model for two observations was performed to express the reliability of the measurements. The reliability coefficient and 95% confidence intervals (CI, to indicate the precision of the point estimates) were calculated for inter-observer variability (comparing the results from the two examiners), for intra-observer variability (comparing the results from the two different tests of each examiner), and for inter-instrument variability (comparing the results from the two different methods—inclinometer and "Flock of Birds"). The inter-observer variability was estimated by comparing the mean value of the two measurements of the first examiner with the respective value of the second one. The reliability coefficients were computed for each motion test. Poor reliability was defined for reliability coefficients between 0 and 0.4, fair and good reliability between 0.4 and 0.75, and high or excellent reliability over 0.75. All statistical analyses were performed using the Statistical Package for Social Sciences (SPSS 16.0, Chicago, IL, USA).

Results

The mean values [±standard deviation (SD)] of cervical range of motion obtained with the inclinometer were 64.0° (9.0) for flexion, 66.8° (13.1) for extension, 40.1° (6.0) for right lateral bending and 37.3° (6.3) for left lateral bending (Fig. 2). The mean (SD) values for total range of motion

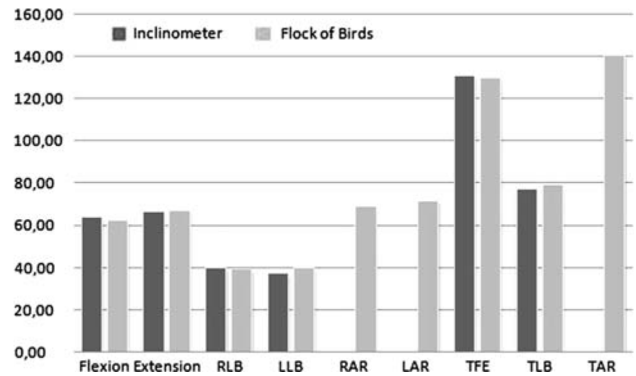

Fig. 2 Mean values of flexion, extension, *RLB* right lateral bending, *LLB* left lateral bending, *RAR* right axial rotation, *LAR* left axial rotation, *TFE* total range of motion for flexion-extension, *TLB* total lateral bending and *TAR* total axial rotation obtained with the inclinometer and the "Flock of Birds" system. Note that rotational movements cannot be evaluated with the inclinometer

with the inclinometer were 130.9° (19.6) for flexion-extension and 77.4° (11.4) for total lateral bending (Fig. 2). The respective values obtained with the "Flock of Birds" system were 62.8° (9.7) for flexion, 67.2° (12.9) for extension, 39.3° (5.4) for right lateral bending, 40.1° (6.6) for left lateral bending, 69.0° (8.4) for right axial rotation and 71.9° (8.1) for left axial rotation (Fig. 2). The mean (SD) values for total range of motion were 130.0° (19.7) for flexion-extension, 79.4° (11.0) for total lateral bending and 140.9° (15.9) for total axial rotation (Fig. 2).

Inter-observer variability

The correlation between the examiner's results in flexion, extension, right lateral bending and left lateral bending using the inclinometer method was high with intraclass correlation coefficients ranging from 0.91 to 0.96. Similar results were obtained when the MTD method was used by both examiners for flexion-extension, left-right lateral bending and left-right axial rotation. The intra-class correlation coefficients ranged from 0.90 to 0.95 (Table 1).

Table 1 Inter-observer variability

	Inclinometer ICC (95% CI)	Flock of birds ICC (95% CI)
Flexion	0.91 (0.69–0.98)	0.91 (0.68–0.98)
Extension	0.96 (0.86–0.99)	0.95 (0.83–0.99)
Right lateral bending	0.94 (0.80–0.98)	0.90 (0.68–0.98)
Left lateral bending	0.96 (0.87–0.99)	0.94 (0.77–0.98)
Right axial rotation		0.92 (0.73–0.98)
Left axial rotation		0.93 (0.75–0.98)

Intra-class correlation coefficient values (ICC) and 95% confidence intervals (CI) for the inclinometer and the magnetic tracking device

Table 2 Intra-observer variability

	Examiner 1		Examiner 2	
	Inclinometer ICC (95% CI)	Flock of birds ICC (95% CI)	Inclinometer ICC (95% CI)	Flock of birds ICC (95% CI)
Flexion	0.79 (0.39–0.94)	0.84 (0.52–0.96)	0.86 (0.57–0.96)	0.91 (0.69–0.98)
Extension	0.92 (0.74–0.98)	0.93 (0.76–0.98)	0.89 (0.62–0.97)	0.89 (0.63–0.97)
Right lateral bending	0.70 (0.21–0.92)	0.60 (0.03–0.88)	0.80 (0.40–0.95)	0.69 (0.18–0.91)
Left lateral bending	0.84 (0.51–0.96)	0.70 (0.21–0.72)	0.84 (0.51–0.96)	0.82 (0.44–0.95)
Right axial rotation		0.87 (0.58–0.97)		0.75 (0.30–0.93)
Left axial rotation		0.75 (0.30–0.93)		0.81 (0.43–0.95)

Intra-class correlation coefficient values (ICC) and 95% confidence intervals (CI) for the inclinometer and the magnetic tracking device methods used by both examiners

Intra-observer variability

The reliability coefficients for the repeated measurements from each examiner were high for flexion and extension in both examiners with either the inclinometer (ICC ranging from 0.79 to 0.92) and the MTD (ICC ranging from 0.84 to 0.93). Fair to good reliability was observed in the measurements of the first examiner with the MTD method for right and left lateral bending. The respective values of the first examiner with the inclinometer method were higher compared to the “Flock of Birds” system, although only in left lateral bending the reliability was high (ICC of 0.84). The measurements of the second examiner in lateral bending displayed high reliability, except from the measurements of right lateral bending with the MTD. High reliability was obtained from the repeated measurements from each examiner in axial rotation using the MTD method alone (ICC ranging from 0.75 to 0.87) (Table 2).

Inter-instrument variability

Measurements obtained from both methods demonstrated high to excellent correlation for all motions. Comparing the results from inclinometer and MTD method from the first examiner, the ICC values ranged from 0.90 to 0.99 in the first examiner and from 0.88 to 0.99 in the second examiner. Excellent correlation between the two methods was observed by both examiners in flexion and extension (Table 3).

Table 3 Inter-instrument variability

	Examiner 1 ICC (95% CI)	Examiner 2 ICC (95% CI)
Flexion	0.97 (0.92–0.99)	0.97 (0.90–0.99)
Extension	0.99 (0.98–1.00)	0.99 (0.97–1.00)
Right lateral bending	0.90 (0.68–0.97)	0.89 (0.65–0.97)
Left lateral bending	0.91 (0.69–0.98)	0.88 (0.60–0.97)

Intra-class correlation coefficient values (ICC) and 95% confidence intervals (CI) for the comparison between inclinometer and the magnetic tracking device methods used by both examiners

Discussion

Despite the availability of numerous instruments for measuring cervical range of motion, clinicians are looking for easier to use, safer and more accurate and reliable devices. In vivo measurements require techniques which are not too invasive or too complex to perform and that are comfortable for the subject. The “Flock of Birds” system is a highly sophisticated non-invasive measurement method with a very high precision, has a very small measurement error (2°–4° within one session), but the measurement error between sessions is substantially larger (varying from 5° to 16°) [21].

The current study has shown that the assessment of the cervical range of motion can be performed simply and with high intra- and inter-observer reliability in flexion, extension, axial rotation and lateral bending. The high inter-observer correlation indicates that the testing routine is applicable for different examiners. The fair to good intra-observer variability in lateral bending that we found might be a result of additional combined movements of axial rotation and flexion/extension occurring during the performance of lateral bending and also a result of the different experience level of the examiners. Intra-observer repeatability was found to be high during the second day test. Our MTD method was found to be highly comparable with the inclinometer method with an inter-instrument correlation coefficient from 0.88 to 0.99.

Each examination consisted of a trial of two tests in each motion. The American Medical Association (Guides to the evaluation of permanent impairment) allows for a variation of ±10% or 5° of the total motion (which ever is greater) [2]. In our study of ten asymptomatic volunteers, variation of results from the same examiner was consistently within the American Medical Association standard. To reduce random movements of the head sensor caused by the subject's hair and scalp, we used a MRI compatible halo ring on which we attached the sensor. Some goniometric and inclinometer devices measure both cervical and thoracic motion, whereas other methods eliminate thoracic motion, thus measuring true cervical motion [1, 10, 23, 26–30]. In our study to minimise thoracic spine motion, the subject's shoulders were strapped to the chair thus reducing the involvement of the thoracic spine motion and measuring cervical spine motion.

Goniometric and inclinometer devices are suggested as simple tools for clinical use, but for obvious reasons these methods afford no possibilities of three-dimensional measurements of cervical range of motion [1, 9, 27]. The electromagnetic technique described here has the advantage of simultaneous assessment of the overall coupled motions occurring in cervical spine motion as the data is displayed in real time on a computer screen. Various movements contributing to the complex motion pattern of the cervical spine seems to be a characteristic of each individual. Rotation and lateral bending in the lower cervical spine are coupled because of the inclination of the inter-vertebral joints and the function of the uncovertebral joints [15, 22, 26].

A comparison of interclass correlation coefficients was made with results of other available reliability studies.Our ICCs when the inclinometer was concerned were on the average lower than those found by Youdas et al. [30] and Tucci et al. [28] but higher than those found by Nilsson et al. [24]. When the MDT was concerned we observed generally higher ICCs compared to Assink et al. [6].

Some limitations of the present study should be acknowledged. First of all, it was a study that was limited to sample size. Despite the high ICC values observed in the vast majority of the results the CI were wide indicating high probability of uncertainty as a result to the small number of patients. Second, another limitation is the possible source of bias resulting from the fact that the neutral cervical position was not standardised and was based on the assumption of the subjects of a neutral head-neck position by looking at their reflection in the mirror. However, we have used the same technique used by all other studies reporting on the same method. Third, the present study was performed in healthy individuals and it is unknown whether the observed reliability would be reproduced if symptomatic subjects were used. It has been reported that it is more difficult to obtain reliable results of range of motion measurement in symptomatic patients compared to non-symptomatic [5]. Another limitation of the study is that it could not account for bias resulting from coupled movements when measuring the cervical range of motion. In cases of inter-observer reliability no significant differences were observed between the two examiners, probably due to the fact that the mean values of the two measurements of each examiner were compared. When intra-observer reliability was calculated a significant variability between the two measurements of the examiner was observed in lateral bending, as a result of this coupled cervical movement that exists in lateral bending. Finally, we cannot exclude differences in the measurements by both methods due to changes in viscoelasticity of the neck. However, we believe that such bias was eliminated by the fact that the subjects were examined on two consecutive days at the same time of day in a random order of the examiners.

Conclusions

In conclusion, our study demonstrates that the MTD "Flock of Birds" is a reliable, noninvasive, reproducible method to measure cervical range of motion. The method described here is well suited for the assessment of various degenerative and traumatic (soft tissue injuries) disorders of the cervical spine. It could also be performed in the evaluation of postoperative results in cervical spine surgery as a function of time and in the evaluation of the influence of different therapeutic procedures postoperatively. The results of this method could serve to standardise or customise rehabilitation.

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