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ScienceDirect
Manual Therapy 13 (2008) 450–455
MANUAL THERAPY
www.elsevier.com/math

Original Article

Assessment of the cervical range of motion over time, differences between results of the Flock of Birds and the EDI-320: A comparison between an electromagnetic tracking system and an electronic inclinometer

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Received 10 November 2005; received in revised form 30 April 2007; accepted 23 May 2007

Abstract

The objective of this study was to analyse cervical range of motion, assessed over time by means of a digital inclinometer (EDI-320) and a three-dimensional electromagnetic tracking device (Flock of Birds).

The maximum active cervical range of motion was assessed with two measurement devices in three sessions over time, with 6-week intervals. In total, 26 women and 24 men (mean age: 44.4, SD: 9.9) without known pathology of the cervical spine participated. Four movements were measured axial rotation with the cervical spine in a flexed and in an extended position, flexion–extension, and lateral bending.

The results showed that the factor time was significant for rotation in extension and rotation in flexion. The factor device was significant for all movements measured, and the interaction term between time and device was significant for all movements except rotation in extension.

The Flock of Birds measured significantly higher ranges of motion on all motions except for lateral bending. A substantial variation in cervical range of motion was observed over time (ranging from −5.6 to 8.1) as well as between devices (ranging from −13.1 to 29.9).

Substantial and significant differences in cervical range of motion were found over time as well as differences between the Flock of Birds and the EDI-320.

Keywords: Range of motion; Assessment; Natural variation; Reliability

1. Introduction

Measuring the range of motion of the cervical spine is an important clinical issue, since it is used to measure impairments and treatment effects. Because of its complex anatomical structure the cervical spine range of motion is difficult to assess (Bogduk and Mercer, 2000). Although there is a substantial amount of evidence for the validity and reliability of different measurement devices, there is no gold standard for measuring cervical range of motion (Chen et al., 1999; Antonaci et al., 2000; Lantz et al., 2003). Each measurement device has its own advantages and disadvantages. Simple devices, such as goniometers, are easy to handle and are mostly used in clinical

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1356-689X/$ - see front matter
doi:10.1016/j.math.2007.05.012

practice. More sophisticated devices, which are mostly used in laboratories, require extensive training, sophisticated software and are usually more time-consuming. However, few comparisons of simple and sophisticated devices have been performed. One study, showed good agreement between a three-dimensional ultrasound motion device (Zebris) and a gravity goniometer (Myrin) (Malmstrom et al., 2003).

In a clinical setting, usually the range of motion is assessed over time; we therefore conducted a longitudinal study comparing the EDI-320 with the Flock of Birds (FOB). The EDI-320 is an electronic inclinometer, a small and mobile device, which is easy to handle. Studies demonstrate that the EDI-320 has a good intraobserver (ICC: 0.93 and higher) and interobserver reliability (ICC: 0.89 and higher) (Chiarello and Savidge, 1993; Tousignant et al., 2001; Pool et al., 2004; de Winter et al., 2004). The Flock of Birds is a sophisticated electromagnetic tracking device, but is not easy to use in a clinical setting, because of an extensive calibration procedure and is not portable (Meskers et al., 1999). Previous studies indicated that this system has a high precision and a good intraobserver (SD: between 2° and 4°) and an acceptable to good interobserver reliability (ICC: 0.66 and higher) in measuring active cervical range of motion (Koerhuis et al., 2003; Assink et al., 2005; Bergman et al., 2005). Because natural variation in neck mobility over time is an important factor in cervical range of motion measurement (Bergman et al., 2005), we performed measurements in three sessions, with a 6-week interval. The natural variation represents the variation in the range of motion which occurs over time naturally. This variation is not the result of an intervention.

The aim of this study is to analyse cervical range of motion, assessed over time by means of a digital inclinometer (EDI-320) and a three-dimensional electromagnetic tracking device (Flock of Birds).

2. Materials and methods

2.1. Subjects

Fifty healthy volunteers, 26 women and 24 men (mean age: 44.4, SD: 9.9) without known pathology in the neck and shoulder region were invited to participate. The subjects were mostly employees of the Centre for Rehabilitation at the University Medical Centre Groningen. Informed consent was obtained from all the volunteers.

2.2. Measuring devices

The Flock of Birds (Ascension Technology Corporation, Burlington, USA) is a 6-degrees-of-freedom electromagnetic tracking device, consisting of a standard range transmitter and three receivers. One receiver is mounted on the head, one on the thorax and the third receiver is mounted on a palpation stylus. The receivers on head and thorax are used to measure the range of motion. The receiver with the palpation stylus is used for locating seven bony landmarks on the head and the thorax (nose bridge, chin midpoint, processus xiphoideus, incisura jugularis, protuberantia occipitalis externa, processus spinosus C7 and processus spinosus T8) (Koerhuis et al., 2003). These landmarks are used for constructing a coordinate system which defines the posture of the patient and the position of the receivers on head and thorax. These data are used to calculate the position and orientation of the head relative to the thorax. This position will be recorded and translated into a range of motion. For details, the reader is referred to Koerhuis et al. (2003) and Meskers et al. (1999).

A position calibration procedure was performed prior to the measurements, since the influence of metals in the environment, e.g., iron-strengthened concrete, on data outcome is quite large (Meskers et al., 1999).

The Cybex Electronic Inclinometer-320 (EDI-320) is an electronic inclinometer consisting of a display and a hand-held unit that is used to take the range of motion readings of various joints of the body. The hand-held unit contains an incremental encoder, which converts rotatory displacement into a digital pulse. The encoder should be held vertically because of its gravity-dependency. Differences between the starting and ending positions are converted to degrees in range of motion. Thus, the encoder provides relative values compared to the starting position. The display device indicates range of motion on a 360° scale. Because the EDI-320 must be held against the subjects' head by the observer, it is not possible to measure passive range of motion. Measurements were performed while the subject was seated in an upright position. Axial rotation with the cervical spine in a neutral position while sitting upright could not be measured by the EDI-320, because it cannot measure range of motion in the horizontal plain.

2.3. Measurements

All the measurements were performed by one observer (BK) with equal experience with the EDI-320 and the Flock of Birds. Prior to the study, measurements were standardised and information about the aim of the study and the measurement procedure was given to all the participants. All measurements started with a measurement by the Flock of Birds. The subjects were invited to take place in a chair with armrests facing a mirror and were asked to assume a comfortable and upright position, looking at their own reflection in the mirror. The subjects conducted four movements actively in a fixed sequence: axial rotation with the cervical spine in a flexed and in an extended position, flexion–extension, and lateral bending.

Each movement was repeated three times. The subjects were instructed only to move their head in the desired direction and to avoid compensatory movements in thoracic or lumbar region. During the movements, the subjects were instructed to conduct a maximal movement at a normal velocity until the end of the range of motion was reached. After measuring the four movements with the Flock of Birds, the same movements were measured with the EDI-320. Before the EDI-320 measurements started, the subjects were asked to walk around during a 5-min break. Measurements with the EDI-320 started with stabilising the hand-held unit on the head of the subjects. This position was recorded as the starting position. The subjects were asked to return to this position after each movement.

These measurement sessions were conducted three times in a 6-week interval (baseline (T0), 6 weeks (T1) and 12 weeks (T2)).

3. Statistical analyses

Statistical analysis was performed using SPSS software, version 11.0. Mean of three repetitions was calculated for each movement and used for further analysis. Analyses were based on the total range of motion (for example, flexion plus extension, left plus right rotation). A repeated-measures ANOVA was performed with time, device and time × device interactions as within subject factors. Greenhouse–Geisser adjustment for degrees of freedom was applied for all analyses because of small violations of sphericity. To quantify differences between the devices, the mean difference and the corresponding 95% confidence intervals (95%CI) were calculated per session (post-hoc).

Longitudinal variation in cervical range of motion (between T0 and T1 and between T0 and T2) and differences between the devices in this longitudinal variation were calculated as the mean differences, their standard deviations and corresponding 95%CI (post-hoc).

Variance components were calculated to analyse the contribution of the different factors, patient, time and device, to the measurement results for all four movements. The factors, patient, time and device, were defined as random. All one-way and two-way interaction terms were used. Negative variance components were set to zero. The error variance was calculated as the sum of all variance components minus the subject variance because that is the object of measurement.

4. Results

In Table 1, the mean cervical range of motion per session by device is summarised. In Table 2, the significance of the results of the repeated-measures ANOVA is summarised. The factor time was significant for rotation in extension and rotation in flexion. The factor device was significant for all movements measured, and the interaction term between time and device was significant for all movements except rotation in extension.

The Flock of Birds measured significantly larger range of motion in rotation in extension, rotation in flexion and flexion–extension compared to the EDI-320, but significantly smaller range of motion for lateral bending at all measurement sessions. The mean difference between the Flock of Birds and the EDI-320 varied from −13.1 (95%CI: −16.6 to −9.7) for lateral bending at T2 to 29.9 (95%CI: 24.4–35.4) for rotation in extension at T0 (Table 3).

Variation in time differed between the Flock of Birds and the EDI-320. It varied from −3.4 (95%CI:−6.3 to 0.4) for lateral bending T0–T2 to 7.8 (95%CI: 3.5–12.0) for flexion–extension T0–T1 (Table 4).

Variance components are summarised in Table 5. The variance attributed to device was largest for all movements. Over 97% of the error variance could be attributed to the main effect of device.

Table 1
Mean cervical range of motion, per session by device

Movement	Measurement sessions		
	Baseline (T0)	6 weeks (T1)	12 weeks (T2)
Rotation in extension			
FOB, mean (SD)	97.9 (18.1)	100.7 (19.9)	103.7 (18.6)
EDI-320, mean (SD)	68.0 (15.7)	71.9 (23.3)	74.2 (22.4)
Rotation in flexion			
FOB, mean (SD)	88.8 (11.2)	88.5 (11.0)	91.2 (14.3)
EDI-320, mean (SD)	72.1 (12.6)	77.7 (14.1)	80.2 (14.6)
Flexion–extension			
FOB, mean (SD)	130.8 (16.3)	125.1 (19.2)	126.6 (17.2)
EDI-320, mean (SD)	107.8 (13.8)	109.9 (14.0)	109.0 (13.4)
Lateral bending			
FOB, mean (SD)	77.4 (14.2)	77.2 (14.3)	77.4 (15.1)
EDI-320, mean (SD)	87.2 (14.2)	89.2 (16.0)	90.6 (14.5)

Table 2
Significance of the factors device, time and device–time interactions (device × time), results of repeated-measures ANOVA

	p			
	Rotation in extension	Rotation in flexion	Flexion–extension	Lateral bending
Time	0.002	<0.001	0.346	0.128
Device	<0.001	<0.001	0.002	<0.001
Device × time	0.871	0.004	0.002	0.045

Greenhouse–Geisser adjustment for degrees of freedom was applied for all analyses because of violation of sphericity.

Table 3
Mean differences between devices and 95% confidence intervals (95%CI), per session

Movement	Measurement sessions		
	Baseline (T0)	6 weeks (T1)	12 weeks (T2)
Rotation in extension			
Differences between devices (95%CI)	29.9 (24.4 to 35.4)	28.8 (22.3 to 35.2)	29.4 (23.8 to 35.1)
Rotation in flexion			
Differences between devices (95%CI)	16.7 (12.5 to 20.8)	10.8 (6.9 to 14.7)	11.0 (6.4 to 15.6)
Flexion–extension			
Differences between devices (95%CI)	23.0 (19.3 to 26.7)	15.2 (10.8 to 19.6)	17.7 (14.1 to 20.9)
Lateral bending			
Differences between devices (95%CI)	−9.8 (−13.1 to −6.5)	−12.0 (−15.5 to −8.5)	−13.1 (−16.6 to −9.7)

If the neutral value of no difference (0) is not included in the confidence interval (95%CI) the difference is significant ($p<0.05$).

Table 4
Variation over time in cervical range of motion and differences between devices

Movement	T0–T1		T0–T2	
	Mean difference (SD)	95%CI	Mean difference (SD)	95%CI
Rotation in extension				
FOB, mean(SD)	2.8 (14.0)	−1.5 to 7.1	5.8 (13.8)	1.6 to 10.0*
EDI-320, mean(SD)	4.0 (13.6)	−0.2 to 8.2	6.2 (14.5)	1.8 to 10.7*
Differences between devices	1.2 (16.9)	−4.0 to 6.4	0.4 (17.1)	−4.8 to 5.7
Rotation in flexion				
FOB, mean(SD)	−0.3 (10.1)	−3.3 to 2.8	2.5 (11.8)	−1.1 to 6.1
EDI-320, mean(SD)	5.6 (5.8)	3.8 to 7.3*	8.1 (9.3)	5.3 to 10.9*
Differences between devices	5.9 (11.8)	2.3 to 9.4*	5.6 (14.2)	1.3 to 10.0*
Flexion–extension				
FOB, mean(SD)	−5.6 (13.1)	−9.5 to −1.8*	−4.2 (12.2)	−7.8 to −0.6*
EDI-320, mean(SD)	2.2 (9.2)	−0.5 to 4.9	1.2 (9.6)	−1.6 to 4.1
Differences between devices	7.8 (14.4)	3.5 to 12.0*	5.4 (13.5)	1.5 to 9.4*
Lateral bending				
FOB, mean(SD)	−0.3 (7.4)	−2.4 to 1.9	0.0 (7.5)	−2.2 to 2.2
EDI-320, mean(SD)	2.0 (8.0)	−0.4 to 4.3	3.4 (7.6)	1.1 to 5.6*
Differences between devices	−2.2 (9.2)	−4.9 to 0.5	−3.4 (10.0)	−6.3 to 0.4

*If the neutral value of no difference (0) is not included in the confidence interval (95%CI) the difference is significant ($p< 0.05$).

5. Discussion

Cervical range of motion varies significantly and considerably over time for rotation in extension and rotation in flexion. The range of motion assessed by means of the Flock of Birds was significantly higher compared to those assessed by means of the EDI-320 for all movements except lateral bending in which the EDI-320 measured significantly higher values. The significance of the interaction term between time and device for three of the movements assessed indicates that the effects of time differ per device. The Flock of Birds is a sophisticated measurement method with good intraobserver and interobserver reliability (Koerhuis et al., 2003; Assink et al., 2005). The EDI-320 has a good intraobserver and interobserver reliability also (Chiarello and Savidge 1993; Tousignant et al., 2001; Pool et al., 2004; de Winter et al., 2004). Despite this observer reliability, the two devices are not interchangeable.

In all measurement sessions the Flock of Birds was the first device used, followed by the EDI-320 device. This fixed sequence might influence the outcome of the measurements because the subject knows what to expect and soft tissues may be pre-stretched, supposing a larger range of motion. However, the range of motion measured with the EDI-320 was less compared to the Flock of Birds, except for lateral bending. Previous research showed good agreement between a three-dimensional ultrasound motion device and a gravity-reference goniometer was found. However, in that

Table 5
Variance components for each movement with measurement conditions each entered as random factors (all two-way interactions were calculated)

	Rotation in extension	Rotation in flexion	Flexion–extension	Lateral bending
Variance components				
Patient	195.078	107.289	149.722	159.471
Time	8.709	6.438	0.083	0.353
Device	7471.550	6681.153	14077.877	7037.181
Patient × time[a]	22.669	0.000	6.547	4.660
Patient × device	138.372	53.701	30.183	44.397
Device × time[a]	0.000	0.000	0.000	0.000
Residual variance	58.376	44.963	61.439	22.541
Sum	7894.754	6893.544	14325.851	7268.603
% of error variance				
Time	0.113	0.095	0.001	0.005
Device	97.037	98.451	99.307	98.988
Patient × time[a]	0.294	0.000	0.046	0.066
Patient × device	1.797	0.791	0.213	0.625
Device × time[a]	0.000	0.000	0.000	0.000
Residual variance	0.758	0.663	0.433	0.317

Residual variance: the variance that cannot be attributed to other source of variation.
Error variance: All variance components added except the main effect of patient.
[a]Negative variance components were set to 0.

study, measurements were performed with the two devices simultaneously (Malmstrom et al., 2003). We were unable to measure range of motion with both the devices simultaneously, since the Flock of Birds operates in an electromagnetic field and is disturbed by other metals in the field, such as the EDI-320. To reduce disturbing influences on the range of motion as much as possible, the measurement session with the Flock of Birds was directly followed by the measurement session with the EDI-320. However, some differences in outcomes of the range of motion may have occurred because the subjects were repositioned.

Variance in measurement results can be attributed to several sources including patient, time, measurement device, the differences between the devices over time and the observer. These sources can produce random or systematic variation in measurement outcome. The systematic differences are the significant differences either found between the devices or over time or for the interaction term between device and time (Table 2). Because the data obtained by using the FOB were directly stored in a personal computer the influence of the one observer used on the readings of the FOB cannot be analysed. The random errors are the non-significant differences over time and the non-significant interaction between device and time for rotation in extension (Portney and Watkins, 2004). The above-mentioned sources of variation are also reflected in the variance components analyses in which device accounted for more than 97% of the error variance for all movements.

A previous study showed that the Flock of Birds had a small measurement error within one session but a substantially larger measurement error between sessions (Koerhuis et al., 2003). This difference in measurement error within one session and between two sessions may have influenced our results since we measured two devices over time.

The substantial variation in cervical range of motion over time was also described by Bergman et al. (2005), using the Flock of Birds. Our results showed this variation over time to be significant for rotation in extension and rotation in flexion for the Flock of Birds as well as the EDI-320.

Variation over time was on an average larger measured with the Flock of Birds (Table 4). An explanation might be that the Flock of Birds measured a larger range of motion for most of the movements compared to the EDI-320 and as a result larger variation may be expected.

The substantial differences in the range of motion between devices in the current study and the variation over time clearly show that the measurement device is an important factor in the interpretation of cervical range of motion measurement. This finding indicates that data obtained in clinical settings with the EDI-320 cannot be compared to norm values obtained by means of the Flock of Birds. More generally, it may be questioned whether norm values obtained by means of a three-dimensional measuring device can be compared to norm values obtained by a two-dimensional measuring device, especially when combined movements are measured. During performance of movements of the cervical spine, a coupling effect may occur indicating that during a movement in one direction, for instance rotation, also the angle of flexion and lateral bending changes

(Feipel et al., 1999; Hof et al., 2001). This coupling effect is especially strong for the combined movements of the cervical spine (Feipel et al., 1999). However, the data of our study shows that the differences between the devices do not restrict themselves to the combined movements but also to flexion and extension and lateral bending (significant device effect and a significant time device interaction effect). Further, the findings of coupled movements have been interpreted as a measurement artefact caused by the rotation sequence (Hof et al., 2001).

In conclusion, cervical range of motion varies significantly and considerably over time for rotation in extension and rotation in flexion. The range of motion assessed by means of the Flock of Birds was significantly higher compared to those assessed by means of the EDI-320 for all movements except lateral bending in which the EDI-320 measured significantly higher values. A significant interaction term between time and device exists.

Acknowledgements

This study was supported by grants from the 'Stichting Anna Fonds'.

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