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Range of global motion of the cervical spine: intraindividual reliability and the influence of measurement device

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Abstract Range of motion tests are often employed in the quantification of musculoskeletal impairment and in the assessment of the efficacy of therapeutic interventions. The aim of the present study was to compare the absolute values for, and the day-to-day reliability of, measures of cervical spinal mobility made with two computerised motion analysis devices. The ranges of cervical flexion, extension, lateral bending, axial rotation, and axial rotation in flexion and extension were determined for 19 volunteers using both the CA6000 Spine Motion Analyser and the Zebris CMS system; all measures were repeated on a second occasion 1–3 days later. The test-retest reliability was good for each instrument: there was no significant difference between the mean values derived on the two separate days ($P>0.05$), and the corresponding intraclass correlation coefficients were 0.75–0.93 for all primary movements and 0.57–0.93 for axial rotation in flexion or in extension. For each primary movement, a small but significant difference (1–10%; $P<0.05$) between the values derived from the two instruments was observed, the systematic nature of which was revealed by the excellent correlation coefficients between them. For the measures of axial rotation in flexion or in extension, however, there was not only a poor correlation between the data obtained from the two devices, but the mean values also differed significantly. Each device is highly reliable in itself and can be used with confidence in longitudinal studies. The establishment of 'normal' values for the primary motions should take account of the slight differences observed between devices. Normal values for rotation in flexion or extension cannot be established until the source of the device-dependent difference is identified.

Key words Cervical spine · Global mobilityMotion analysis devices · Reliability · CA6000

Introduction

Range of motion tests are useful in the quantification of musculoskeletal impairment, and may also be used to provide a basis for assessing the efficacy of therapeutic interventions [11]. To successfully distinguish between normal and abnormal motions of the spine, reliable and accurate measurement techniques are required. The American Medical Association has long considered dual inclinometry to be the standard clinical methodology for the 'non-invasive' assessment of spinal range of motion [5]. More recently, assessments have been made with computerised motion analysis devices, which have also been employed to monitor relative changes in curvature of the spine during movement or during the adoption of differing postures [1, 6, 7]. The use of such instruments for the assessment of range of motion has the advantage that continuous (online) measurement of the changing profile of the spine can be made up to the end-range position, and these devices might therefore be expected to produce more accurate and reliable values than single measurements made by an examiner at the subject's declared end-point, which must then be sustained whilst the measurement is made.

Although these systems offer a number of potential advantages in comparison with the more traditional 'static' measures of range of motion, there is some concern regarding the comparability of the values yielded by the differing devices [13]. In response to work highlighting discrepancies in previously reported measurements of cervical spine range of axial rotation [13], Dvorak [8] stated that range of motion is without doubt an important parameter and that the next necessary step is a comparison of the different devices available in terms of their reliability and intra- and interobserver repeatability. Despite this, a recent meta-analysis concluded that reliability has still not been adequately tested for the majority of technologies employed in the measurement of cervical motion [4]. If guidelines are to be established regarding recommended 'healthy' levels of mobility, it is imperative that differing devices yield comparable results.

The aim of the present study was to compare the global range of motion of the cervical spine using two computerised motion analysis devices.

Subjects and methods

Twenty-two volunteers with no history of serious neck pain, and no pain at the time of testing, agreed to participate. Nineteen of them (10 men, 9 women) performed all the necessary tests over the 2-day testing period and presented complete data sets (two subjects could only attend on 1 day, and the data file from one subject on the 2nd day was accidentally lost). Their physical characteristics are shown in Table 1.

Table 1 Physical characteristics of the subjects (mean ± SD, range)

Parameter	Men (*n* = 10)	Women (*n* = 9)
Age (yrs)	29.7±7.9 (23–47)	31.9±10.9 (23–55)
Body mass (kg)	73.8±8.3 (64–90)	63.0±14.0 (45–95)
Height (m)	1.78±0.10 (1.69–1.98)	1.70±0.07 (1.54–1.76)

Motion analysis devices

System 1: CA6000 Spine Motion Analyser. The CA6000 (Orthopaedic Systems Inc., Calif.) has been described in detail previously [8, 12]. Briefly, the system is an electromechanical device comprising six high-precision potentiometers in a linkage system that allows unrestrained three-dimensional (3D) motion. Changing the relative angles of the linkage system results in a change in resistance of the corresponding potentiometers, and this is recorded in real time on a personal computer.

The upper linkage arm of the CA6000 was attached to a short metal post on the rear of a helmet positioned firmly on the subject's head, and the lower linkage arm was attached to the back-support of a chair on which the subject was seated and in which they were restrained in terms of shoulder movement (Fig. 1).

System 2: Zebris CMS. The Zebris CMS system (Zebris Medizintechnik GmbH, Isny, Germany) is a somewhat newer and less well-investigated device, which comprises a helmet equipped with a series of three ultrasonic transmitters, the signals from which are detected by means of three microphone sensors positioned on a stand close by (Fig. 1).

The CA6000 and Zebris helmets were affixed to the head simultaneously, to allow direct comparison of the two systems during a given movement, and thereby obviate potential errors due to inconsistencies in the subject's repeat performances.

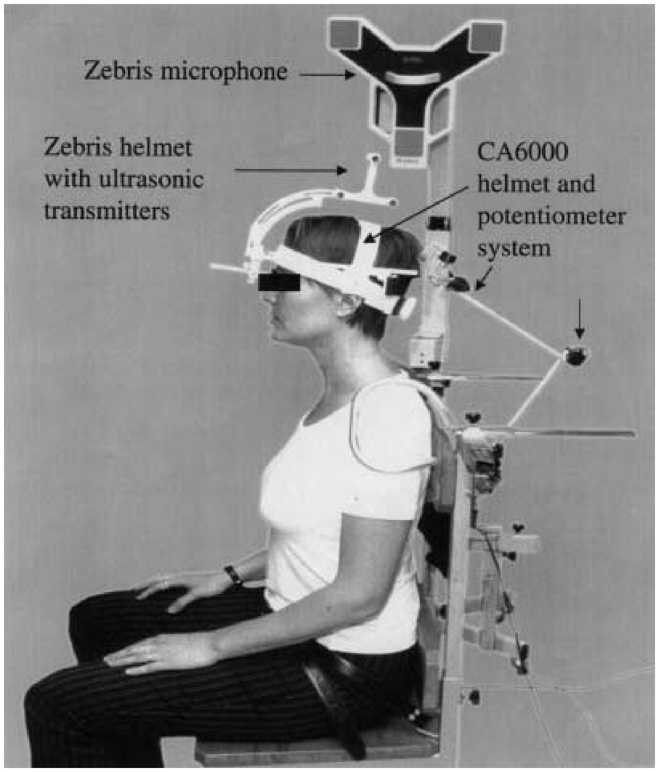

Fig. 1 Two devices (CA6000 and Zebris) simultaneously affixed to the subject and used for the measurement of cervical range of motion

Movements examined

The subjects attended for testing on two separate occasions, 1–3 days apart, and each subject was tested at the same time each day. The movements investigated comprised lateral bending, flexion/extension, axial rotation, and axial rotation whilst the head was fully extended and whilst the head was fully flexed. Before each test, the motion was explained to the subject and was demonstrated by the examiner. The subject was then asked to place his/her head in a neutral position, and the devices were 'zeroed'. The subject was asked to move through the full range of motion as far as possible, and to continue repeating the movement until asked to stop by the examiner (after seven full movement cycles).

Data analysis and statistics

A previous study using a similar protocol to that described above showed that the most reliable data are obtained from taking the average values for range of motion from the fourth to the sixth cycles [12]. These average values were therefore used in the present study to represent an individual's range of motion in each plane.

The reliability of repeated measurements made on separate days using the *same* device was assessed with a repeated measures analysis of variance (ANOVA) followed by determination of the intraclass correlation coefficient, (ICC).

A paired *t*-test was used to assess differences in the mean values for a given variable obtained using the two different measurement systems. The relationship between the measures obtained using the two devices was also examined, using the Pearson-product correlation. These two statistical methods respectively provide an indication of the significance of the difference between the mean values for each system and the consistency of the relative 'ranking' of individuals within the group using the two systems. In order to examine the level of agreement between the two instruments, the method recommended by Bland and Altman [2] was used. Here, the difference between values obtained using the two methods (Zebris minus CA6000) is first plotted against the mean of the two values, for each individual data point. The agreement between the two methods is given by the mean and standard deviation of the differences; a non-zero value suggests a systematic error or bias, and positive values indicate larger values for the Zebris. It has been suggested [2] that the two methods can be used interchangeably, provided differences between the devices within the mean difference ±2SD would not be considered clinically important. These 2SD boundaries are referred to as the 'limits of agreement'. Statistical significance was accepted at the 5% level.

Results

Reliability of each motion analysis device

There was no significant difference between day 1 and day 2 for any of the range of motion values, and the intraclass correlation coefficients were between 0.75 and 0.93 for the primary movements and between 0.57 and 0.93 for the movements involving rotation in either flexion or extension (Table 2). The devices displayed similar reliability for each test movement.

Gender differences in range of motion

For the primary movements of flexion, extension, lateral bending and axial rotation, no significant gender differences in the ranges of motion were observed. For the movements of axial rotation made in extension and in flexion, the women generated significantly lower values than the men (by approximately 15%; $P < 0.0001$). As the aim of the study, however, was to compare the devices for reliability and comparability, all subsequent analyses were considered for men and women collectively.

Table 2 Test-retest reliability measures for range of motion, showing the significance of the difference (*P*-value) and intraclass correlation (ICC) between the measurements taken on day 1 and day 2

Parameter	Day 1 Mean (±SD)	Day 2 Mean (±SD)	*P*-value	ICC
Flexion				
Zebris	60.7° (10.9°)	62.0° (13.5°)	0.50	0.88
CA6000	59.0° (10.5°)	60.9° (13.8°)	0.37	0.85
Extension				
Zebris	67.1° (12.9°)	68.7° (10.4°)	0.49	0.78
CA6000	59.9° (10.6°)	62.2° (10.8°)	0.29	0.75
Flex.+ext.				
Zebris	127.8° (17.9°)	130.7° (21.1°)	0.38	0.86
CA6000	118.8° (16.7°)	123.1° (21.3°)	0.22	0.82
Lateral bending				
Zebris	85.1° (13.4°)	85.0° (17.3°)	0.96	0.92
CA6000	82.7° (12.5°)	82.9° (12.3°)	0.91	0.89
Axial rotation				
Zebris	150.8° (12.4°)	151.8° (13.9°)	0.52	0.93
CA6000	144.3° (12.3°)	146.3° (14.0°)	0.23	0.92
Axial rotation flex.				
Zebris	93.1° (19.0°)	94.4° (17.5°)	0.55	0.93
CA6000	114.5° (18.5°)	121.3° (22.7°)	0.13	0.74
Axial rotation ext.				
Zebris	85.1° (20.0°)	91.3° (19.2°)	0.22	0.57
CA6000	111.0° (19.3°)	115.9° (21.3°)	0.27	0.73

Table 3 Comparison of the mean (SD) values[a] for ranges of motion determined with Zebris and with CA6000 systems, showing the correlation coefficients (*r*) and the *P*-values (significance of the difference between the two measurements)

Motion	Range (degrees)		*P*-value	*r*
	Zebris	CA6000		
Flexion	61.3 (12.1)	59.9 (12.1)	0.0001	0.99
Extension	67.9 (11.6)	61.1 (10.6)	0.0001	0.92
Flex.+ext.	129.3 (19.3)	121.0 (19.0)	0.0001	0.97
Lateral bending	85.1 (13.2)	82.8 (12.2)	0.0013	0.95
Axial rotation	151.3 (13.0)	145.3 (13.0)	0.0001	0.97
Axial rotation flex.	94.0 (18.2)[b]	117.2 (20.8)[b]	0.0001	0.52
Axial rotation ext.	88.2 (19.6)[b,c]	113.5 (20.2)[b]	0.0001	0.64

[a] Data taken from the trials performed both on day 1 and day 2
[b] Significantly lower than the value for axial rotation in the neutral position for the same measuring device
[c] Significantly lower than the value for axial rotation in flexion for the same measuring device

Comparison of CA6000 and Zebris devices

The mean values for each range of motion, the significance of the difference between them, and the correlation between individual values derived from the two devices are shown in Table 3.

For each primary movement, a small but significant difference (1–10%) between the mean values was observed, the systematic nature of which was revealed by the very high correlation coefficients between the values derived using the two devices. In each instance, the Zebris system yielded higher values than the CA6000.

For the range of flexion, the limits of agreement for the two devices were quite narrow: +5.5° to –2.7° (Fig. 2 A), i.e. in 95% of cases the Zebris could be expected to yield measurements that were between 5.5° higher and 2.7° lower than the CA6000. The mean difference between the two devices was minimal (+1.4°). For extension, the corresponding values were +16.5° and +2.3°, with a mean difference of +6.9° (Fig. 2 B). When flexion and extension were considered together, the limits of agreement were between +18.3° and –1.7° and the mean difference was +8.3° (Fig. 2 C). As the mean value for the range of flexion and extension is approximately 125°, this extent of agreement between the two methods can probably be considered acceptable.

For the range of lateral bending, the limits of agreement between the two devices were +10.9° to –5.9°, with a mean difference of just +2.3° (Fig. 2 D).

The two devices were comparable for the range of axial rotation: mean difference was +6.0°, and the limits of agreement were +12.0° to 0° (Fig. 2 E).

For the measures of axial rotation in flexion or in extension, the mean values not only differed significantly (this time with the CA6000 yielding the higher values), but there was also a poor correlation between the data obtained from the two devices. This lack of comparability between the devices was also reflected by the extremely wide and totally unacceptable limits of agreement for the two methods: –61.8° to 15.4° for rotation in flexion, and –59.0° to 8.5° for extension, with corresponding mean differences between the devices of 23.2° and 25.3°, respectively (Fig. 2 F, G).

For both devices, the absolute mean values for axial rotation out of neutral were significantly lower than those performed in the neutral position ($P<0.05$). For the Zebris system only, the values in flexion were significantly lower than those in extension ($P<0.05$).

Discussion

The present study sought to compare the day-to-day reliability of, and level of agreement between, two systems used for the assessment of range of motion of the cervical spine. The systems examined were both computerised motion analysis devices, but worked on differing principles and measurement methods. The CA6000, an electromechanical device, has been used in numerous studies concerned with establishing normative data for individuals of differing age and gender [4, 9, 12], and for identifying deficits in mobility associated with certain disorders of the cervical spine [11]. The Zebris, which operates using an ultrasound emission and detection system, is a somewhat newer technology, the reliability and application of which have only recently been subject to rigorous testing [3].

When assessing changes in range of motion over time, for example in monitoring progress during rehabilitation, it is important to ensure that the device employed is capable of yielding precise measurements, i.e. ones that are repeatable on a day-to-day basis. In this respect, both systems examined in the present study showed excellent reliability for all the primary movements, confirming consistency of both device attachment and subject performance. The results for axial rotation in flexion and in extension were less impressive, but this is not wholly surprising as these movements are much more difficult to execute correctly, and can be uncomfortable to perform, fatiguing the neck muscles after repeated cycles. These factors would be expected to contribute to a less reliable performance. In summary, then, for the movements of flexion-extension, lateral bending and axial rotation, each device examined in the present study can be considered reliable and suitable for use in longitudinal studies, where changes in mobility over time or following interventions are to be quantified.

In accepting a new technology into current use, the issue of reliability is not the only factor to consider. It is also essential to confirm that the device is accurate, i.e. that it measures what it purports to measure. This is particularly important if standards are to be set regarding rec-

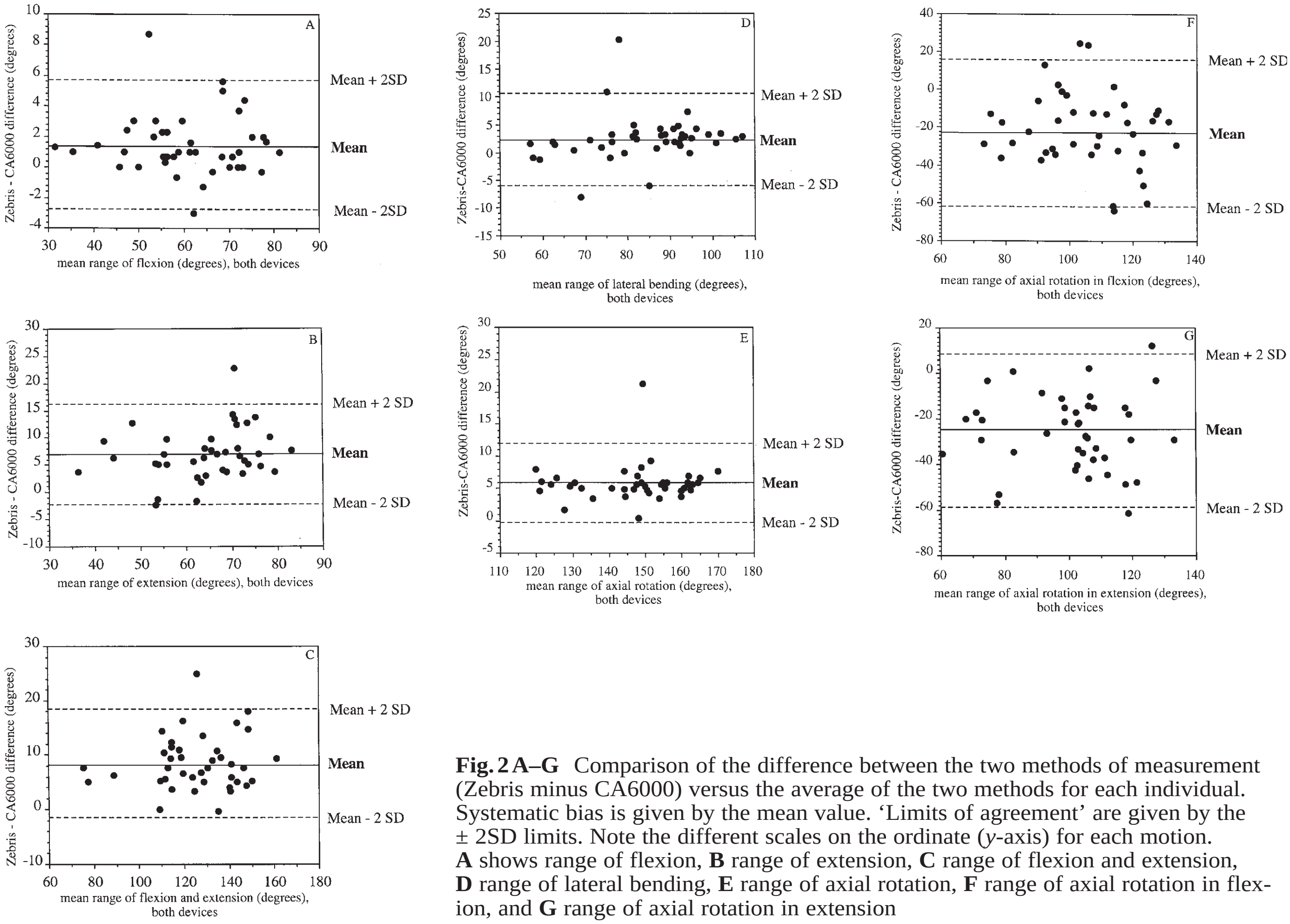

Fig. 2 A–G Comparison of the difference between the two methods of measurement (Zebris minus CA6000) versus the average of the two methods for each individual. Systematic bias is given by the mean value. 'Limits of agreement' are given by the ± 2SD limits. Note the different scales on the ordinate (*y*-axis) for each motion. **A** shows range of flexion, **B** range of extension, **C** range of flexion and extension, **D** range of lateral bending, **E** range of axial rotation, **F** range of axial rotation in flexion, and **G** range of axial rotation in extension

ommended levels of mobility, for the purposes of assessing the extent of an individual's injury, need for rehabilitation, or job suitability. In order to make such assessments of accuracy, an established and reliable 'gold standard' is required, with which the new system can be compared. With regard to the accuracy of measures of cervical spinal mobility, this is difficult to do, because no suitable gold standard currently exists. Although radiographic measures of range of motion are commonly considered to represent the ideal, no study has ever demonstrated acceptable reliability for X-ray measures of global cervical range of motion [4]. If this technique has not been shown to be reliable, then it can not be adopted as a gold standard, and the best that can be done is to ensure agreement between other instruments/procedures that purportedly measure the same phenomenon [4, 12].

Comparisons between the ranges of motion measured using the two devices in the present study yielded acceptably concordant results for the primary movements of flexion/extension, lateral bending, and axial rotation, with the latter demonstrating the narrowest limits of agreement (i.e. the best agreement) between methods. The differences in mean values for each device, although statistically significant, were mostly small and systematic. Hence, if required, the interpretation of normal values could be adjusted accordingly for device. The potential 'random' error that is sometimes introduced by intraindividual differences in performance when investigating two or more devices was eliminated in the present study by examining the two devices simultaneously. The differences observed must therefore have concerned the manner in which the devices either recorded, or calculated, angular displacements in the given plane of the movement. In this respect, the most extreme discrepancy was between the measures of axial rotation made with the head either flexed or extended.

Measurements of axial rotation out of flexion and extension are considered to be important in the differential evaluation of mobility of the upper and lower regions of the cervical spine, and are often advocated as part of the clinical evaluation [10]. Rotation out of maximum flexion is considered to measure rotation of the upper cervical spine, mainly at the atlantoaxial joint [9]. Interestingly, this value has been shown not to decrease with age (whereas the contribution to rotation from the lower segments *does*), but rather remains constant or in fact increases slightly to perhaps compensate for the reduced motion in the lower segments [9]. Three previous in vivo studies have shown that the range of axial rotation initiated from a position of flexion or extension is considerably lower than when initiated from the neutral position [3, 9, 15]. Biomechanical explanations for this phenomenon include increased tension in the alar and capsular ligaments and in the fibres of the intervertebral discs, and an unfavourable orientation of the facet joints [15]. In the present study, the percentage reduction in rotation measured with the Zebris system when movements were made out of the neutral position (62% and 56% for flexion and extension, respectively) were similar to those reported for similarly young age groups measured using the same system (68% and 64%; [3]) or an electromagnetic tracking device (67% and 55%; [15]). Slight differences between the studies may have been accounted for by differences in the chin position adopted during the flexion or extension movements; tucking the chin in during flexion and out during extension will generally act to reduce the values for rotation to the greatest extent [15]. Our results for the CA6000 system (80% and 77%, for flexion and extension respectively) differed not only from those obtained with the Zebris system, in this and a previous study [3, 15], but also from those reported previously using the same CA6000 device (41% and 91%, respectively; [9]). The reason for this discrepancy between the CA6000 and the other systems is not clear, but may be to do with the ordering of the matrix manipulations required to convert the raw signals from the different data collection devices (potentiometers and ultrasound microphones) into displacement angles. These discrepancies point to the need for further assessment regarding the validity of these complex motions.

No significant gender differences in the ranges of motion for the three cardinal planes were observed in the present study. This may, at first sight, appear to contradict the conclusions of previous studies indicating that women display higher values than men [9]. However, a closer look at the data reveals that this is not actually so. In the study of Dvorak et al. [9], no significant differences between the sexes in the age groups 20–29 years and 50–59 years were found. In the present study, 64% of the volunteers were between 20 and 29 years old, and a further 4.5% were in the 50–59 years age group (the main aim was to assess reliability in a mixed age group, and no attempt was made to recruit volunteers in specific age groups). Hence, the results are wholly compatible with those of Dvorak et al. [9], as well as others who have failed to see gender differences in groups of young subjects [3, 14, 15].

As both devices examined in the present study appear to be similarly reliable and generate comparable values for the primary ranges of motion, the question naturally arises as to which system the clinician or researcher should choose to employ in the assessment of cervical spinal motion. As well as making measurements of total range of motion, both systems are also capable of making real-time measurements of spinal motion, which naturally extends their functionality to include applications in the fields of biomechanics or occupational ergonomics. In this respect, the Zebris system is somewhat more limited with regard to freedom of movement of the subject, who must remain within a prescribed distance of the microphones to ensure that the ultrasonic signals are conveyed accurately from the transmitters. With the CA6000, the whole device can be attached to the patient (the rear support can be attached to a light harness worn by the subject, rather than being attached to the back of the chair on which the subject sits; this method yields equally accurate values of range of motion [12]) such that the only limitation is the length of cable interfacing the device to the computer The choice of device will thus most likely depend on the precise application for which it is required. For more complex motions, such as rotation in flexion or extension, more research is needed to assess the reliability and validity of the current systems, although it would appear that the Zebris system at least yields values that are consistent across laboratories and comparable with other motion analysis systems.

In conclusion, the CA6000 and the Zebris spine motion analysis systems have been shown to yield reliable and comparable measurements of cervical spinal range of motion in the primary planes of motion.

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