Comparison of Ranges of Cervical Motion Measured by Gravity-Based Goniometry and Ultrasound-Based Motion Analysis System

Shwu-Fen Wang Huei-Ming Chai Tung-Wu Lu*

Background and Purposes: The gravity-based Cervical Range of Motion (CROM) device and the ultrasound-based computerized motion analysis system (Zebris) have both been shown to be highly reliable in measuring cervical range of motion (ROM). The ranges of cervical motion of healthy young subjects measured by these two devices, however, were reported to be different in values. Whether this discrepancy is the result of sampling or instrumentation bias is unknown. The purpose of this study was to examine the relationship between the ranges of neck motion measured simultaneously by the gravity-based CROM device and the ultrasound-based Zebris motion analysis system. **Methods:** Forty healthy subjects aged from 19-45 years were recruited. The subjects wore the head attachment of the Zebris system, on which the CROM device was superimposed. The subjects were asked to perform maximum neck movements in flexion/extension and side-bendings at the self-determined comfortable speed. Pair t-test, limit of agreement, and regression analysis were used to test the difference, clinical consistence, and relationship, respectively, of the ROMs measured from these two devices. **Results:** For the ranges measured during flexion, and side-bending, there were no significant differences between the values obtained from these two devices; while for those measured during extension, there was a significant difference ($p < 0.05$). The measured ROMs by the CROM and Zebris were linearly related ($p < 0.05$) in all directions of neck movements with the R^2 ranging from 0.67 to 0.89, and β values ranging from 0.82 to 0.94. The limits of agreement for the movements in side-bendings ranged from -5.38° to 6.37°; and in flexion/extension ranged from -14.12° to 9.60°. **Conclusions:** During extension, the discrepancy exists between cervical ROMs measured by the CROM and Zebris. The ROMs of the neck side-bending and flexion, however, showed no difference between the values obtained by these two devices. These results indicated that although these two devices were based on different principles, both might approach the same values in side-bending. The issue of the consistency of measurement instrument should be settled before comparing the ranges of extension of the cervical spine measured by these two devices. (FJPT 2002;27(3):124-130)

Key Words: Cervical spine, Measurement, Range of motion

School and Graduate Institute of Physical Theraphy, College of Medicine, National Taiwan Universaty

* Institute of Biomedical Engineering, National Taiwan University

Correspondence to: Shwu-Fen Wang, School and Graduate Institute of Physical Therapy, College of Medicine, National Taiwan University, No. 7, Chung-Shan South, Rd., Taipei 100, Taiwan. Tel: (02)23123456-7668

Email: sfwang@ccms.ntu.edu.tw

Received: Mar 31, 2002 Accepted: Apr 17, 2002

Introduction

The development of the gravity-based goniometers, such as the Cervical Range of Motion (CROM), has greatly improved the efficiency and reliability of the measurement of the range of neck movement.[1-3] The CROM is characterized by two gravity-based goniometers, each one for the movement in the sagittal and frontal plane respectively, and one compass-based goniometer for the measurement of the movement in the transverse plane. The design of the CROM with these meters attached on a head set and affixed to the head of the subjects facilitates the efficiency of the measurement of the cervical range of motion (ROM), and eliminates errors caused by inconsistent palpation. Moderate to high reliability (ICC＝0.66-0.90) of the CROM has been demonstrated in the literature.[1,4-6] The validity of the CROM has been demonstrated by the high correlation (r＝0.97-0.98 for the sagittal plane) of the measurement with radiographic method, which was considered as a gold standard in the measurement of cervical ROM.[6] One of the major limitations of the CROM, however, is that the device only provides static measurements, therefore, requires the subject to stay in the maximum range for a few seconds to record the value on the meters manually for a single measurement.

Ultrasound-based motion analysis system, such as the Zebris,[7,8] is one of the three-dimensional systems developed by incorporating computer technology to provide dynamic, continuous and functional measurement of the range of motion.[9-12] It has been demonstrated to be accurate and reliable.[7,13] The absolute deviation of the ultrasound-based motion analysis system during calibration with the digital inclinometers by the triple-joint assembly of a camera tripod is less than 1˚.[7] In addition, the test-retest reliability of the ultrasound-based motion analysis system was reported to be high (ICC＝0.75-0.93) along the principal directions.[13]

The main concern during the measurement of neck motion, however, is that the recorded values from different devices[6,10,13,14] are highly correlated but significantly different, although each of these devices is highly reliable. For example, neck ROMs measured by the ultrasound-based motion analysis system (Zebris) and potentiometers-linkage system (CA6000) are both reliable and highly correlated (r＝0.92-0.99) in the principal directions, yet small but significant difference exists.[13]

Normal ROMs of the cervical spine of large samples of healthy subjects (N＝337 and 157, respectively) of both genders with age ranged from 11 to over 80 years have been established using CROM and Zebris system, respectively.[4,8] However, the ranges measured by the Zebris system are 10˚ larger than those by the CROM. For example, for female subjects aged from 20 to 50 years, the range during flexion/extension measured by CROM was 113.2˚-134.5˚;[4] whereas by the Zebris system it was 121.3˚-152.1˚.[8] Greater discrepancies in ROMs measured by different devices have also been encountered in the transverse plane. For example, cervical rotation of healthy young subjects measured from computer tomography(CT), radiographic, and compass-based goniometer of CROM ranged from 105-144 degrees,[15-17] while CA6000 registered an average of 183.8˚±11.8˚.[18]

This discrepancy might be due to various factors, including differences in procedures, sampled population, or instruments. In order to rule out discrepancies due to differences in instruments or different population, cervical ROMs were measured simultaneously with these two devices on the same group of subjects for comparison in this study. However, because the compass-based goniometer of CROM was subjected to the influence of the magnetic field generated by the Zebris system, direct comparison between ranges simultaneously measured by these two systems is not valid. This study, thus, was designed to investigate the relationship between the ranges measured by the gravity-based goniometer of CROM and by the Zebris system in the sagital and frontal planes. The questions to be answered were:(1) Was there any difference between the ranges of cervical movements measured by Zebris and CROM systems in the sagittal and frontal planes? (2) Was this range difference clinically acceptable if they did exist? (3) Did any statistically significant relationship exist between the ranges measured by the Zebris system and those by the CROM device?

Methods

Forty healthy young subjects (aged 19-45 years) were recruited from the community by poster announcement. None of the subjects had received any medical treatment for neck problems.

Cervical ranges of motion in sagittal and frontal planes were measured using both the gravity-based goniometer (the CROM, Performance Attainment Associates, 958 Lydia Drive, Roseville, MN 55113, USA) and the ultrasound-based motion analysis system, (the Zebris motion analysis system, Zebris Medizintecknik GmbH, Wilhelmstrasse 134, D-72074, Tubingen, Germany). The Zebris system included a CMS 70P measuring system and the Windata 2.11 software (Zebris Medizintecknik GmbH, Wilhelmstrasse 134, D-72074, Tubingen, Germany). There were a sound wave transducer sensor stand, a basic unit, a head attachment with a triplet marker set, and a shoulder cap with a triplet reference marker set in the CMS 70P measuring system. The special head attachment and the shoulder cap permited a quick and reproducible fastening on the head and shoulder, respectively. The triplet marker set on the head attachment was used to measure the kinematics of cervical motions. The triplet reference marker set with the shoulder cap was used to establish a local shoulder reference coordinate so that the calculation of cervical motions would not be confounded by any movements from the trunk or other body parts below. Three miniature ultrasound transmitters, which generate sound pulses at 35Hz, were located on each of the triplet marker set. The transducer sensor consisted of three microphones supplied by a current of 1.5A (5V).

The spatial coordinates of the triplet markers were continuously monitored by measuring the sound pulses transmitted between the ultrasound transmitters and the microphones in the transducer sensor. The sampling rate of the sound pulses was set at 25Hz at the sensor. The coordinate information recorded by the sensor was then forwarded to the basic unit of the system, and acquired by a personal computer by using the WinData 2.11 software. The WinData 2.11 software was used to calculate the range of cervical motions in 3D space with respect to the shoulder reference coordinate.

Table 1. Ranges of cervical motions measured with CROM and Zebris system in four directionss.

Motion	CROM Mean (SD)	Zebris Mean (SD)	*p*-value	Limit of Agreement
Flexion	52.9 (8.1)	52.2 (8.9)	0.361	-11.12-9.60
Extension	79.1 (17.0)	76.5 (16.6)	0.007*	-14.12-8.96
Left side-bending	39.4 (7.3)	39.2 (6.7)	0.673	-5.38-5.02
Right side-bending	40.8 (7.6)	40.1 (7.1)	0.129	-4.95-6.37

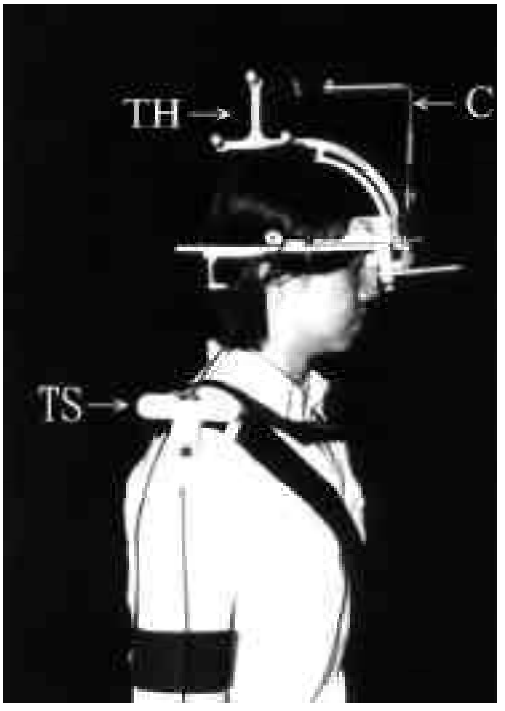
Ranges of motion and limit of agreement: degrees was defined by the range of mean difference plus and minus two standard deviation.
* p<005, significant difference between the ROMs measured with the CROM and Zebris systems

Table 2. Regression model of neck motion between the ranges measured with the Zebris (X) and CROM (Y).

Direction	R^2	β	*P*	Equation Y＝B0＋B1X
Flexion	0.67	0.82	0.000	Y＝5.00＋0.89X
Extension	0.89	0.94	0.000	Y＝3.98＋0.92X
Left side-bending	0.87	0.93	0.000	Y＝5.36＋0.87X
Right side-bending	0.86	0.93	0.000	Y＝4.96＋0.86X

Procedure

In order to eliminate the potential error while placing these two neck ROM measurement systems, the head attachment of the Zebris system was superimposed on the CROM device (Figure), and affixed to the head of the subject with a velcro strap. Four directions of cervical motion in the sagittal and frontal planes, namely flexion/extension and side-bending to both sides, were examined. Two raters were employed for the experimental procedures. One rater placed the head mount, and took the readings of the meters of the CROM device, while the other rater controlled the computer and delivered oral instructions. One of the raters was a physical therapist with four years of clinical experience and the other was a senior physical therapy student. All measurements took place during daytime, in a quiet and air-conditioned room, with temperature set at 25˚C.



Figrue The triple markers of head attachment (TH) of the Zebris system were superimposed with the CROM device (C) and was stabilized simultaneously to the head of the subject with a velcro strap. The triple markers of the shoulder cap (TS) were fastened to the right shoulder of the subject.

The experimental protocols, approved by the institutional ethical committee, were explained to the subject, and a written consent form was signed. The subjects sat relaxed in a chair with back support. The feet of the subjects were on the ground and the hands rested freely on the thighs. After a demonstration, the subjects were asked to perform 5 maximum neck movements in 4 directions, which also served as the warm-up exercise and to make sure that the subjects understood the procedure. Shoulder cap and head attachment with ultrasound markers were then attached to the subject's right shoulder and head, respectively. The shoulder cap was fixed to the right shoulder of the subject by a velcro strap. The shoulder and upper trunk of the subject was then fastened to the back of the seat. Therefore, the shoulder motion was limited during the tests.

The subjects were asked to sit in a comfortable upright position, perform maximum cervical flexion/extension movements, and stay in the maximal range for about 2 seconds. While the subject maintained the neck in the terminal range, one rater read the degree in the meter of CROM in the principal direction. Single measurement was performed for movements in the sagittal plane, followed by the movement in the frontal plane. The maximum range for each direction was recorded for statistical analyses. All individual motions were performed at a comfortable self-determined pace. A typical measurement session lasted for 15 to 20 minutes.

Data analysis

The maximal ranges in the sagittal and frontal planes recorded by the Zebris system were compared with those obtained from the CROM using the paired t-test. The "limit of agreement"[19] was used to determine if the measured range different between these two devices were clinically acceptable, which is usually within a range from -5˚ to 5˚. The limit of agreement was defined as the range of mean difference plus and minus two standard deviations ($D \pm 2SD$; D indicated mean differences of each pair of the ranges measured by these two devices). The linear regression model was used to test whether the ranges measured by these two devices were linearly related. In this regression model, the range measured by CROM was considered to be

the independent variable (X) and that measured by Zebris system, the dependent variable (Y). For all tests, the α level was set at 0.05. The statistical procedures were performed using SPSS 10.0 for Windows (SPSS Inc., 444N Michigan Avenue, Chicago, Illinois 60611, USA).

Results

Ranges, significance of the difference, and the ranges of limit of agreement between the ranges measured by CROM and Zebris systems in 4 directions of the cervical spine are shown in Table 1. There were significant differences between the ranges recorded by CROM and Zebris during cervical extension ($p<0.05$, Table 1.), but not during flexion or sidebendings. The limits of agreement for the movement in side-bendings were slightly over the clinical acceptable range and was in the range from -5.38° to 6.37°, while that for the flexion/extension movement ranged from -14.12° to 9.60° (Table 1.).

The linear regression equations between the measured ranges of Zebris (Y) and CROM (X) in 4 directions of neck motion were also significant ($p<0.05$) with R^2 ranging from 0.67-0.89 and β values ranging from 0.82 to 0.94 (Table 2.). The interception constant (B0) of the regression equations during flexion/extension and side-bending ranged from 3.98-5.36, and the slopes (B1) ranged from 0.86-0.92, indicating a good association between the values recorded by these two devices.

Discussion

Cervical ranges of motion measured CROM and Zebris were comparable for neck side-bending movement , but were significantly different for neck extension movement. The ranges of cervical motion measured by the CROM and Zebris system along the sagittal and frontal planes fitted well in a linear model.

In previous studies[6,9,10], cervical motions measured with the CROM and radiographic method were comparable in the sagittal plane, and thus researchers concluded that the CROM has a high validity (0.98-0.99).[6] This condusin, however, was challenged by the fact that significant difference in ranges of motion existed in spite of high correlations between the ROMs measured by different devices. The findings of the present study showed that although the ranges measured by the CROM and Zebris system during extension were highly correlated, yet they were significantly different. Our findings are also consistent with those of Ordway et al. [9], Youdas et al. and Castro et al.,[4,8] which demonstrated a 10° difference in ranges measured during flexion/extension. The design of simultaneous measurement taken with these two devices and the attachment of the CROM on the head set of the Zebris system in this study may have prevented the potential error arising from skin movements and marker positions during repetitive measurements with different devices. Controlling the trunk motion to minimum during the entire experimental process may have also reduced the possible errors arising from trunk motion.

Therefore, in this experiment, the differences recorded during cervical extension were most likely resulted from the designs of each device. While the CROM system registers the final position of the head movement relative to the verticality, and the Zebris system measured the final head position relative to the shoulder triad marker system. Different from the flexion of the neck, extension of the neck is a less frequently occurred motion during daily activities. Subjects were thus possible to use some synergistic movement of shoulder retraction during neck extension. This small movement in the shoulder might cause the discrepancy of the ranges in cervical extension measured by these two devices. The small retraction of the shoulders during neck extension could introduce a small posterior shift of the coordinate generated from the shoulder reference triad, and cause the ROM in extension measured by the Zebris system to become smaller. Therefore, restricting the movement of the shoulder during neck extension might reduce the discrepancy measured by these two devices.

Conclusion

Cervical ranges measured with the CROM and Zebris

were different during neck extension, but during flexion and side-bending. The limit of agreement of the range measured by the devices were slightly larger than the clinical acceptable range of ±5˚ in the frontal plane, and in the range from -15˚ to 10˚ in the sagittal plane. Thus, direct comparison of the ranges measured with different devices during cervical extension needs to be made with caution.

Acknowledgement

The statistical consultations provided by Dr. Tsauo JY, and Dr. Jeng SF are highly appreciated. The authors also would like to show our gratitude to our research assistants, Ms Teng CC and Ms Lee KS. This study was supported by a grant (DOH88-HR-823) from the Department of Health, Taiwan.

References

1.Capuano-Pucci D, Rheault W, Aukai J, Bracke M, Day R, Pastrick M. Intratester and intertester reliability of the cervical range of motion device. Arch Phys Med Rehabil 1991;72:338-40.
2.Nilsson N, Christensen HW, Hartvigsen J. The interexaminer reliability of measuring passive cervical range of motion, revisited. J M Physiol Ther 1996;19:302-5.
3.Tucci SM, Hicks JE, Gross EG, Campbell W, Danoff J. Cervical motion assessment: A new, simple and accurate method. Arch Phys Med Rehabil 1986;67:225-30.
4.Youdas JW, Carey JR, Garrett TR. Reliability of measurements of cervical spine range of motion-Comparison of three methods. Phys Ther 1991;71:98-104.
5.Rheault W, Albright B, Byers C. Intertester reliability of the cervical range of motion device. J Orthop Sports Phys Ther 1992;15:147-50.
6.Tousignant M, de Bellefeuille L, O'Donoughue S, Grahovac S. Criterion validity of the cervical range of motion (CROM) goniometer for cervical flexion and extension. Spine 2000;25: 324-30.
7.Dvir Z, Prushansky T. Reproducibility and instrument validity of a new ultrasonography-based system for measuring cervical spine kinematics. Clin Biomech 2000;15:658-64.
8.Castro WH, Sautmann A, Schilgen M, Sautmann M. Noninvasive three-dimensional analysis of cervical spine motion in normal subjects in relation to age and sex. An experimental examination. Spine 2000;25:443-9.
9.Ordway NR, Seymour R, Donelson RG, Hojnowski L, Lee E, Edwards WT. Cervical sagittal range-of-motion analysis using three methods. Cervical range-of-motion device, 3space, and radiography. Spine 1997;22:501-8.
10.Alund M, Larsson SE. Three-dimensional analysis of neck motion. A clinical method. Spine 1990;15:87-91.
11.Feipel V, Rondelet B, Le Pallec J, Rooze M. Normal global motion of the cervical spine: An electrogoniometric study. Clin Biomech 1999;14:462-70.
12.Trott PH, Pearcy MJ, Ruston SA, Fulton I, Brien C. Three-dimensional analysis of active cervical motion: The effect of age gender. Clin Biomech 1996;11:201-6.
13.Mannion AF, Klein GN, Dvorak J, Lanz C. Range of global motion of the cervical spine: Intraindividual reliability and the influence of measurement device. Eur Spine J 2000;9:379-85.
14.Mayer T, Brady S, Bovasso E, Pope P, Gatchel RJ. Noninvasive measurement of cervical tri-planar motion in normal subjects. Spine 1993;18:2191-5.
15.Mimura M, Moriya H, Watanabe T, Takahashi K, Yamagata M, Tamaki T. Three-dimensional motion analysis of the cervical spine with special reference to the axial rotation. Spine 1989; 14:1135-9.
16.Penning L, Wilmink JT. Rotation of the cervical spine. A CT study in normal subjects. Spine 1987;12:732-8.
17.Youdas JW, Garrett TR, Suman VJ, Bogard CL, Hallman HO, Carey JR. Normal range of motion of the cervical spine: An initial goniometric study. Phys Ther 1992;72:770-80.
18.Dvorak J, Antinnes JA, Panjabi M, Loustalot D, Bonomo M. Age and gender related normal motion of the cervical spine. Spine 1992;17:S393-S8
19.Bland JM, Altman DG. Statistical methods for assessing agreement between two methods of clinical measurement. Lancet 1986;1:307-10.

以頸部角度測量儀及超音波動作分析系統測量頸部關節活動度之比較

王淑芬 柴惠敏 呂東武*

研究背景與目的：以頸部角度測量儀(CORM)及超音波動作分析系統(Zebris)測量頸部關節活動度，在過去文獻中均顯示具優良之測量效度。但以此二種工具測量健康人之頸部關節角度，在不同文獻中之結果不盡相同。如此不同之結果，是由於取樣或儀器之差異仍未知。本篇研究即在探討同時以頸部角度測量儀及超音波動作分析系統測量頸部關節活動度之相關性。**方法：**四十位19-45歲的健康受試者接受頸部關節活動度測量。受試時，頸部角度測量儀及超音波動作分析系統之頭部超音波感應支架互相重疊，且同時戴在受試者的頭部。受試者以自覺舒適速度，作最大角度之頸部的前屈、後仰、及左右側彎方向之動作。統計方法以配對之 t-test、同意度範圍、及線性回歸，檢測兩測量儀器所測得之最大頸部前屈、後仰及左右側彎角度的差異、臨床一致性、及是否具線性關係。**結果：**於頸部前屈及左右側彎時，兩測量儀器之值無明顯差異。於頸部後仰時，兩測量儀器之值有明顯差異。此四方向上，頸部動作之兩測量儀器測量值間均具線性關係。其 R^2的範圍為0.67-0.89，β值為0.82-0.94。同意度的範圍，在左右側彎時範圍為 -5.38度至6.37度。在後仰及前屈方向較大，其值範圍為 -14.12 度至9.60度。**結論：**於頸部前屈及左右側彎時，兩測量儀器之值的差異無統計差異，同意度的範圍略大於臨床可接受之正負五度範圍。於後仰時，兩測量儀器之值有明顯差異，較可能是緣於兩測量儀器測量原理之不同。 (物理治療2002；27(3)：127-130)

關鍵字：頸椎、活動度、測量

台大醫學院物理治療學系暨研究所
* 台大醫學工程研究所
通訊作者：王淑芬 100台北市中山南路七號 電話： 02-23123456-7668
E-mail:sfwang@ccms.ntu.edu.tw
收件日期：91年3月31日 接受日期：91年4月17日