

VALIDATION OF THE SPIN-T GONIOMETER, A CERVICAL RANGE OF MOTION DEVICE

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ABSTRACT

Objective: To test the validity of the Spin-T goniometer for the assessment of cervical range of movement.

Methods: A linear regression analysis for paired neck movements using first a foam head model and then human subjects was performed to quantify the differences between the measurements obtained from the MotionStar, a movement-tracking device, and the Spin-T. A within-subject repeated measures design using simultaneous data acquisition was completed.

Results: The coefficient of determination (R^2) for all planes of cervical range of motion for both model and human data sets was higher than 0.99. The regression equations for the model data showed no significant ($P > .05$) intercept for flexion-extension and lateral rotation. Human data showed statistically significant intercept for flexion-extension (mean, -0.52°) and lateral flexion (mean, 0.81°) at $P < .05$.

Conclusion: This study quantifies the difference between the MotionStar and the Spin-T goniometer and documents the systematic error between the measures. Where the error reached statistical significance, the magnitude of the error was very small ($<1.5^\circ$). The results of this study suggest that the Spin-T goniometer may be used as a valid measuring instrument for cervical range of movement. (*J Manipulative Physiol Ther* 2005;28:604-609)

Key Indexing Terms: *Reproducibility of Results; Cervical Vertebrae; Range of Motion; Articular; Validity*

The classic spinal motions are flexion, extension, lateral rotation, and lateral flexion. Cervical spine movement is difficult to investigate accurately because of its anatomic structure and individual compensatory movements that may be associated with habit, posture, or pain. Motion in the cervical spine may be divided into the upper cervical spine (occiput to C2) and the lower cervical spine (C3 through T1). Movements of the upper cervical spine include flexion-extension and lateral rotation with minimal lateral flexion, whereas in the lower cervical spine, all 4 movements occur.¹ Movements in the cervical spine are determined by the orientation of the facets, passive

tension of the ligaments, muscles, joint capsule, and fibers of the anulus fibrosus.¹

Normal variation of the cervical range of motion (CROM) is influenced by age and sex,²⁻⁴ degeneration, pathology, surgery, or trauma, as well as factors such as pain,^{5,6} muscle spasm, and whether the movement is performed actively or passively.

A subjective, qualitative observation of the range and path of motion is normally performed by clinicians to analyze passive and active movements. Lack of convenient, valid, and reliable instruments may be a reason why measuring instruments are not used in routine clinical practice. Measuring instruments may be time-consuming for the operator and cumbersome for the patient. Decisions regarding intervention and treatment are often based partly on joint motion, and clinicians need to justify their choice of treatment modality based on an objective assessment of the CROM. Many different methods and instruments have been used to assess CROM. Validity of measuring equipment has been reported less frequently than reliability.⁷⁻¹⁰

Concurrent validity is established by comparing test scores with a recognized gold standard, the criterion. If a high concurrent validity is established, then clinical utility is related to the measurement sensitivity and the ease and logistics of the clinical tool in the normal physiotherapy, and rehabilitation setting is considered.

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Sources of support: No external funds were received for this research.

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Paper submitted May 19, 2004; in revised form October 7, 2004. 0161-4754/\$30.00

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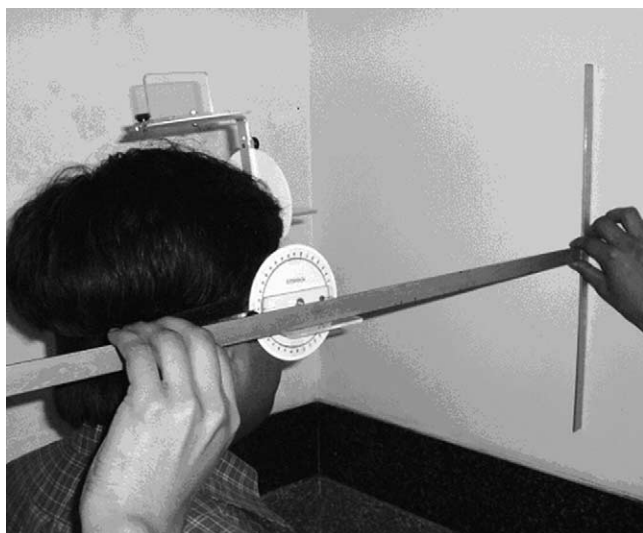


Fig 1. The Spin-T goniometer strapped on the subject's head. The T square is positioned along the spindle of the flexion-extension dial to provide a perpendicular reference to the wall.

The CROM device has been used to report concurrent validity of a single inclinometer.¹¹ The inclinometer was validated for flexion-extension ($ICC = 0.80$) and lateral flexion ($ICC = 0.79$), but not for rotation ($ICC = -0.18$). A study by Haynes and Edmondston¹² showed that the CROM device could not accurately measure natural composite rotation movements. The aim was to establish if the Spin-T and the CROM device could accurately measure natural rotation movement. The devices were placed on a testing instrument which could be positioned at preset angles of rotation with/without a tilt to mimic the lateral flexion that occurs ipsilaterally to and concomitantly with cervical rotation. The Spin-T correlated positively with the testing instrument for rotation with accompanied tilt up to 15° ($ICC > 0.99$), whereas the CROM device showed a poor concordance ($ICC = 0.50$) at rotation with 10° tilt. The concurrent validity of the CROM device has been evaluated against radiographs¹³ in the sagittal plane. In flexion, the coefficient of determination was $R^2 = 0.94$, $r = 0.97$ at $P < .001$. The slope value was 0.98 with a y-axis intercept of -0.08 . In extension, $R^2 = 0.97$, $r = 0.98$ at $P < .001$ with a slope value of 1 and intercept of -2.1 . Radiographs in the flexion-extension view have also been used as a gold standard for a pendulum goniometer.¹⁴ The pendulum goniometer showed a positive correlation ($r = 0.97$) with the radiographs for the entire head on neck motion.

Ultrasound-based motion analyzers have been validated against a precision goniometer¹⁵ and a digital inclinometer.¹⁶ A maximum measurement difference of 0.6° was calculated between the CMS 3D real-time motion analyzer (Zebris Medizintechnik GmbH, Isny, Germany) and the precision goniometer.¹⁵ In clinical terms, a 1° error is

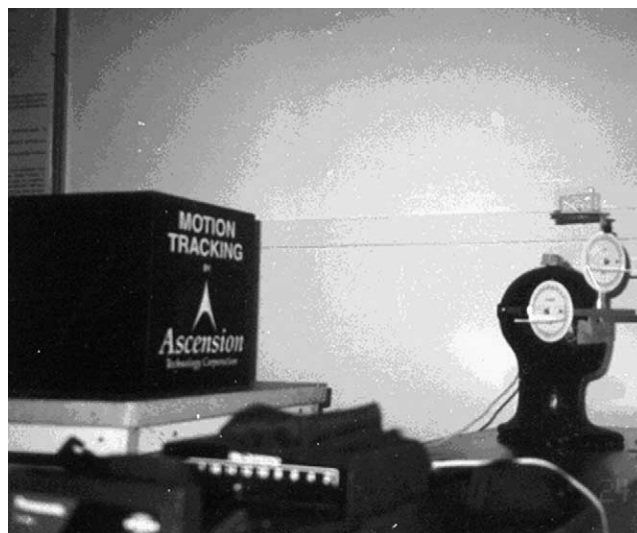


Fig 2. The Spin-T on a foam head model placed in front of a wall. One sensor of the MotionStar can be seen on top of the foam head, whereas the other is placed parallel to it, in front of the foam head. The MotionStar is placed to enable it to track movements of its sensors.

acceptable. The CMS 70P ultrasound system (Zebris Medizintechnik GmbH) was found to be accurate in comparison with the digital inclinometer.¹⁶

Christensen¹⁷ validated the CA 6000 Spine Motion Analyzer (Orthopedic Systems Inc, Union City, Calif) electrogoniometer with two manual protractors. Neck movements in all 6 directions were tested with 4 to 5 recordings measured in each tested direction. The electrogoniometer was not found accurate with the mean difference ranging from 2% to 11.5%. The CA 6000 Spine Motion Analyzer is expensive and ideally suited for research laboratories.

Studies that establish concurrent validity between clinical tests of CROM and gold standard criteria determine the degree of concordance between the two measurements. It is the clinician who then uses this information to consider if the magnitude of the variance between the two systems is small enough to justify the use of the clinical tool.

The Spin-T goniometer has been devised to measure composite cervical spine movements. The purpose of this study was to compare measurements of the simple, clinical cervical spine Spin-T goniometer with that of a high-resolution motion tracking system (MotionStar; Ascension Technology Corporation, Burlington, Vt) for CROM in different planes.

METHODS

Subjects

Four male subjects (age range, 28-45 years) with no history of head or neck pain volunteered to take part in this

Table 1. Comparison of foam model and human regression analysis for movements of the cervical spine

Movement	R	R ²	df	Intercept	t	P	95% CI for intercept		Slope	t	95% CI for slope	
							Lower limit	Upper limit			Lower limit	Upper limit
Flex-ext (f)	.998	.997	22	-0.43	-1.01	.32	-1.33	0.45	0.99	0.66	0.96	1.01
Flex-ext (h)	.999	.998	82	-0.52	-3.93	**	-0.79	-0.26	0.98**	4.50	0.97	0.99
Lat flex (f)	1.000	.999	22	-0.35	-2.48	**	-0.64	-0.05	1.02**	-4.60	1.01	1.03
Lat flex (h)	.998	.997	76	0.81	4.67	**	0.46	1.15	1.01	-1.85	1.00	1.02
Lat rot (f)	1.000	1.000	22	-0.09	-0.66	.51	-0.39	0.20	1.01**	-3.00	1.00	1.02
Lat rot (h)	1.000	.999	70	-0.11	-1.06	.28	-0.31	0.09	0.98**	4.33	0.981	0.99

Double asterisks indicate significance. Flex, flexion; ext, extension; lat, lateral; rot, rotation; f, foam model; h, human head.

study. The study was approved by the Human Rights Committee of the University of Western Australia.

Study Design

The concurrent validity of the Spin-T goniometer was tested for movement in 3 cardinal planes using the MotionStar 3D position sensor as the gold standard. The comparisons were undertaken using a foam head model and also using control volunteers.

Equipment

MotionStar. CROM was assessed using a DC magnetic motion capture system (Ascension Technology Corporation, Burlington, Vt), integrated with purpose-designed software (Labview V5.0, National Instruments, Austin, Tex). The MotionStar tracks the location and movement of one or more sensors in a designated field at approximately 86 Hz, and the Euler angles are transposed to angles in the cardinal planes. The Euler transformation was checked using a triaxial protractor of known accuracy (0.5°).

Spin-T goniometer. The Spin-T goniometer¹² consists of a spectacle-type aluminum frame, positioned on the nose with velcro straps. Three 360° dials (marked at 1° intervals) attached to the frame lie in orthogonal planes reflecting the principal movement planes. An L-shaped rectangular plastic spindle pivots around the center of each dial (Fig 1) with the horizontal portion of the L touching the dial (a red line at one end of the spindle coinciding with the degree markings of the dial along its circumference). The orientation of each dial is referenced and zeroed to the perpendicular plane of the laboratory wall. This is achieved by the use of a light-weight, rigid aluminium T square oriented specifically for each dial (Fig 1). Once the reference position is established, the degrees of relative movements in each plane is assessed by using the T square to reset the spindle on each dial. From this, excursion in that plane is documented.

Testing Protocol

The validity of the Spin-T goniometer was tested in 3 cardinal planes using the MotionStar, which tracked and

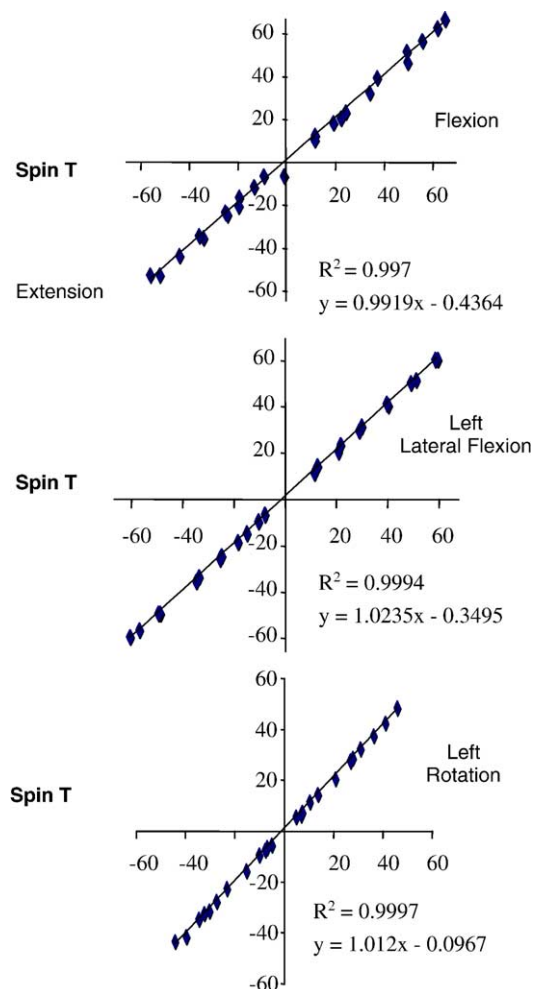


Fig 3. The regression plots and equations for dual cervical spine range of motion determination using the MotionStar and Spin-T Instruments on a foam model head. A, Cervical extension-flexion. B, Lateral flexion. C, Lateral rotation. All measurements are in degrees.

reported composite cervical movement in 3 planes simultaneously. Experimentally, it has been proved that the Spin-T is capable of measuring lateral rotation with concurrent

Table 2. Range of 95% CI for intercept and slope values for model and human measurements

	Foam model	Human
Intercept		
Flexion-extension	1.78	0.53
Lateral flexion	0.58	0.69
Lateral rotation	0.60	0.41
Slope		
Flexion-extension	0.04	0.01
Lateral flexion	0.02	0.02
Lateral rotation	0.01	0.01

lateral flexion reliably and accurately.¹² However, with the design of the Spin-T, it was possible to measure movement in only one plane at one time. Hence, concurrent movements in other planes could not be measured simultaneously. The comparisons were undertaken using a foam head model and also using control volunteers.

Two sensors of the MotionStar were placed parallel to each other, one on the reference table and one on top of the foam head model (Fig 2). The purpose of this was to allow pure movements in specific planes. The model was moved in increments of angles in all 3 reference planes and held in a stable position while readings of the Spin-T goniometer and the MotionStar were recorded simultaneously. A total of 72 paired data sets were recorded during flexion-extension and lateral flexion and rotation movements.

The second step of validity testing was undertaken to reflect the clinical setting. Four men performed a series of incremental CROM tests that covered their available range. A total of 234 readings in flexion, extension, lateral flexion, and lateral rotation for each subject were taken.

Statistical Analysis

A repeated measures design using a linear regression model was used. Simultaneous data acquisition of CROM was performed for a series of ranges of motion in all cervical movements, namely, flexion-extension and lateral flexion (left and right) and rotation (left and right). Paired data sets of movements in all 6 directions were compared for the MotionStar data and the Spin-T data using, first, a linear regression model analysis and, secondly, 95% limits of agreement. Coefficients of determination (R^2) were calculated and confidence intervals (CIs) assessed for systematic change in the intercept. $P < .05$ was adopted as the criterion for accepting statistical differences.

RESULTS

Model Head Comparison

The model head data showed a positive correlation with the MotionStar with R values higher than 0.998 for displacements in all directions. Table 1 shows the regression data for

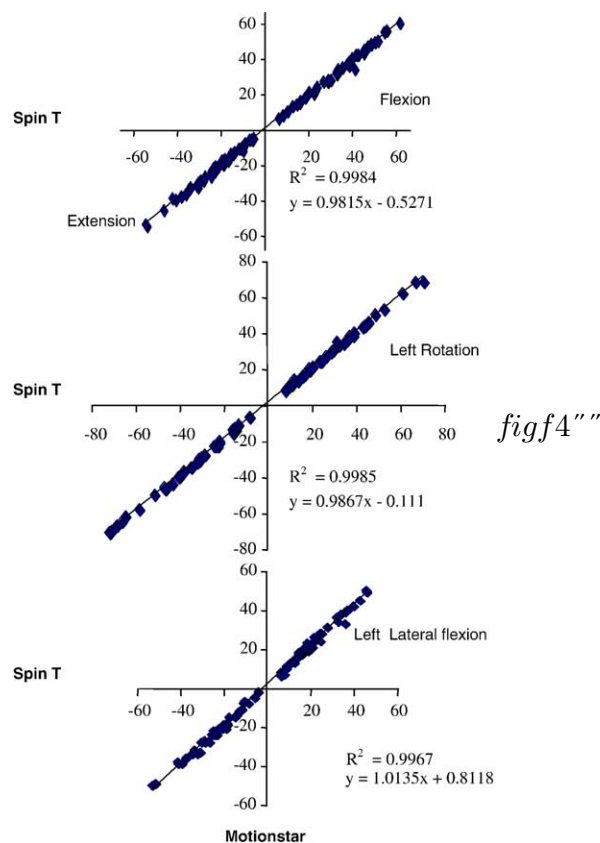


Fig 4. The regression plots and equations for dual cervical spine range of motion determination using the MotionStar and Spin-T Instruments with 4 subjects. A, Cervical extension-flexion. B, Lateral rotation. C, Lateral flexion. All measurements are in degrees.

induced movements of the cervical spine using a model head. The regression data illustrates a high coefficient of determination ($R^2 > 0.991$) for individual movements with a mean root mean square error of 1.0° . Scatter diagrams (Fig 3) for linear regression analysis were constructed for Spin-T vs MotionStar measurements.

R^2 values were close to 1. Most of the variation of the measurements obtained with Spin-T compared with the independent variable, the MotionStar, are shown in Fig 3. For all movements, the intercept was not significantly different from zero ($P < .05$) except for lateral flexion, which showed a mean error of -0.35° (95% CI, -0.64 to -0.05 ; $P < .05$). The slope values for lateral flexion (1.023) and lateral rotation (1.01) were significantly different from 1. However, the lower and upper 95% CI for both movements included 1, and the difference was small (Table 2).

Human Data Comparisons

Spin-T measurements of humans showed a high coefficient of determination ($R^2 > 0.982$) for all discrete neck movements and R^2 higher than 0.997 for paired movements

(Fig 4). Slope values for flexion-extension and lateral rotation differed significantly from 1, whereas the slope value for lateral flexion at 1.01, with its lower 95% CI limits equal to 1, was not significant (Table 1). Intercepts not exceeding 1.5° were significant from zero for flexion-extension (mean, -0.5°) and lateral flexion (mean, 0.8°). Lateral rotation did not show a systematic bias.

DISCUSSION

Compared with human data, the foam head model measurements were more accurate. Reasons for this difference may be attributed to the fact that while testing humans, there would be inadvertent movement, whereas the head model could be fixed into a stationary position. Another explanation is that the number of head model measurements ($n = 72$) were fewer compared with human measurements ($n = 234$). As a result, the 95% CI were reduced and smaller differences detected (Table 2). This is apparent when comparing the similar value intercepts and their respective range of the 95% CI values for flexion-extension (head model: intercept = -0.43° , range = 1.78° ; human: intercept = -0.52° , range = 0.53°). Therefore, these results suggest that although the bias is similar, it is the sample size that contributes to the detection of these systematic differences in the human test conditions. However, as human measurements are only slightly less exact (Table 2), it confirms that the Spin-T measurements can be considered accurate when measuring cervical spine movements in human subjects.

Statistical significance may not always translate to clinical relevance. The spread of error, as indicated by the root mean square value, is $<2^\circ$. The source of this error may be explained by the error in the intercept and slope values. For human measurements, the intercept values for flexion-extension, lateral flexion, and lateral rotation are all within 1.5° . Hence, there is a constant error of only 1.5° between the Spin-T measurements and the MotionStar (underestimation for flexion-extension and lateral rotation and overestimation for lateral flexion), which, although statistically significant, is well within minimal clinical difference considering the natural within-subject variation of CROM.¹⁸ This minimal difference of 1.5° may actually arise from the clinician recording to the nearest degree. The MotionStar does not have this particular source of error, although it may be susceptible to error because of distortions in the magnetic field or software interpolation. Hence, it may be concluded that Spin-T measurements reflect the MotionStar to within 1.5° error. However, what is important to note is that these error values are sufficient to detect meaningful clinical changes. The slope explains the linear scaling error according to the actual range. Accounting for the 0.5° constant error for flexion-extension and no constant error for lateral rotation, these sources of error are relatively small compared with routine clinical assessments for CROM.

The Spin-T goniometer fulfills all aspects of criterion and external validity. Criterion validity justifies the validity of the measuring instrument by comparing measurements made to a well established "gold standard" of measurement. Readings from the Spin-T goniometer were simultaneously compared with readings from the MotionStar. The regression statistics showed that there is a high concordance across the full range of movement during different cardinal planes of assessment. The Spin-T also has external validity because it was used on a group of normal subjects without any laboratory conditions, except for the normal standardization procedures. Hence, a similar methodology can easily be replicated in a clinical trial or in routine clinical practice for assessment of CROM.

The Spin-T is portable and easy to arrange. The maximum time required is 3 minutes from sitting the patient in position to removing the instrument from the patient's head. The Spin-T uses a nearby wall to reference the angle and permits an accurate method of measuring composite cervical movements. The Spin-T has also been proved as a reliable instrument on 23 subjects with a high intraexaminer reliability (>0.87 and >0.91 for each examiner, respectively) and an interexaminer reliability higher than 0.75 for different neck movements.¹²

The Spin-T can be used in a clinical trial and, as well, can provide the clinician an efficient method to measure objectively natural cervical movements in a clinical setting. The findings of this study suggest that the Spin-T is a valid form of CROM assessment and, therefore, may provide the clinician with an alternative to more technical and expensive research alternatives such as the electrogoniometer¹⁷ and ultrasonography.¹⁵

CONCLUSION

The Spin-T goniometer is accurate to within 2° in all planes and ranges when compared with 3D electromagnetic assessments. Hence, the Spin-T goniometer may provide a valid assessment of composite and natural CROM.

REFERENCES

1. White AA, Panjabi MM. Clinical biomechanics of the spine. 2nd ed. Philadelphia: JB Lippincott; 1990. p. 86-122.
2. O'Driscoll SL, Tomenson J. The cervical spine. *J Clin Rheum Dis* 1982;8:617-28.
3. Wolfenberger VA, Bui Q, Batenchuk GB. A comparison of methods of evaluating cervical range of motion. *J Manipulative Physiol Ther* 2002;25:154-60.
4. Youdas JW, Garrett TR, Suman VJ, Bogard CL, Hallman HO, Carey JR. Reliability of measurement of cervical spine range of motion—comparison of three methods. *Phys Ther* 1992;72:770-80.
5. Cassidy JD, Quon JA, LaFrance LJ, Yong-Hing K. The effect of manipulation on pain and range of motion in the cervical spine: a pilot study. *J Manipulative Physiol Ther* 1992;15:495-500.
6. Jordan A, Mehlsen J, Ostergaard K. A comparison of physical characteristics between patients seeking treatment for neck pain

- and age-matched healthy people. *J Manipulative Physiol Ther* 1997;20:468-75.
7. Bulgheroni MV, Antonaci F, Ghirmai S, Sandrini G, Nappi G, Pedotti A. A 3D kinematic method for evaluating voluntary movements of the cervical spine in humans. *Funct Neurol* 1998;13:239-45.
 8. Christensen HW, Nilsson N. Natural variation of cervical range of motion: a one-way repeated-measures design. *J Manipulative Physiol Ther* 1998;21:383-7.
 9. Petersen CM, Johnson RD, Schuit D. Reliability of cervical range of motion using the OSI CA 6000 spine motion analyser on asymptomatic and symptomatic subjects. *Man Ther* 2000;5:82-8.
 10. Youdas JW, Carey JR, Garrett TR. Reliability of measurement of cervical spine range of motion: comparison of three methods. *Phys Ther* 1991;71:78-106.
 11. Hole DE, Cook JM, Bolton JE. Reliability and concurrent validity of two instruments for measuring cervical range of motion: effects of age and gender. *Man Ther* 2000;1:36-42.
 12. Haynes MJ, Edmondston S. Accuracy and reliability of a new protractor based neck goniometer. *J Manipulative Physiol Ther* 2002;25:579-86.
 13. Tousignant M, de Bellefeuille L, O'Donoghue S, Grahovac S. Criterion validity of the cervical range of motion (CROM) goniometer for cervical flexion and extension. *Spine* 2000;25:324-30.
 14. Herrmann DB. Validity study of head and neck flexion-extension motion comparing measurements of a pendulum goniometer and roentgenograms. *J Orthop Sports Phys Ther* 1990;11:414-8.
 15. Natalis M, Konig A. Noninvasive, accurate and reliable measurement of cervical spine motion with a 3D real-time ultrasound motion analyzer. *Ultraschall Med* 1999;20:70-3.
 16. Dvir Z, Prushansky T. Reproducibility and instrument validity of a new ultrasonography based system for measuring cervical spine kinematics. *Clin Biomech (Bristol, Avon)* 2000;5:658-64.
 17. Christensen HW. Precision and accuracy of an electrogoniometer. *J Manipulative Physiol Ther* 1999;22:10-4.
 18. Jordan K, Dziedzic K, Jones PW, Ong BN, Dawes PT. The reliability of the three dimensional FASTRAK measurement system in measuring cervical spine and shoulder range of motion in healthy subjects. *Rheumatology (Oxford)* 2000;39:382-88.

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