Improving Visual Estimates of Cervical Spine Range of Motion

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Abstract

Cervical spine range of motion (ROM) is a common measure of cervical conditions, surgical outcomes, and functional impairment. Although ROM is routinely assessed by visual estimation in clinical practice, visual estimates have been shown to be unreliable and inaccurate. Reliable goniometers can be used for assessments, but the associated costs and logistics generally limit their clinical acceptance.

To investigate whether training can improve visual estimates of cervical spine ROM, we asked attending surgeons, residents, and medical students at our institution to visually estimate the cervical spine ROM of healthy subjects before and after a training session. This training session included review of normal cervical spine ROM in 3 planes and demonstration of partial and full motion in 3 planes by multiple subjects. Estimates before, immediately after, and 1 month after this training session were compared to assess reliability and accuracy.

Immediately after training, errors decreased by 11.9° (flexion-extension), 3.8° (lateral bending), and 2.9° (axial rotation). These improvements were statistically significant. One month after training, visual estimates remained improved, by 9.5°, 1.6°, and 3.1°, respectively, but were statistically significant only in flexion-extension.

Although the accuracy of visual estimates can be improved, clinicians should be aware of the limitations of visual estimates of cervical spine ROM. Our study results support scrutiny of visual assessment of ROM as a criterion for diagnosing permanent impairment or disability.

Assessment of cervical spine range of motion (ROM) is an integral aspect of the physical examination for cervical conditions,[1-3] surgical outcomes,[4] and functional impairment.[1] In fact, the emphasis being placed on such functional measures before and after treatments is increasing.[4,5]

Cervical spine range of motion is routinely used as an outcome measure in clinical studies.[6-8] Underscoring the importance of defining cervical spine ROM, studies have found it to be a preoperative predictor of outcomes of anterior cervical surgery,[9] and other studies have suggested it is a determinant of athletes' return to play.[10]

Spinal ROM measurements can be used to determine the degree of disability experienced by a patient with a spinal condition as defined in the *Guides to the Evaluation of Permanent Impairment* by the American Medical Association (AMA).[1] In the medicolegal realm, ROM measurements made by clinicians can influence the dollar amounts of awards in legal claims, and, according to the AMA guides, the difference in cervical spine ROM between normality and disability or impairment can be as little as 5°.

Although cervical spine ROM is routinely assessed and documented in clinical practice, no universal protocol exists for its evaluation.[11,12] In fact, considerable inter-examiner variation in visual estimates of ROM has been found,[13-16] and significant inaccuracies have been reported.[17,18]

Goniometers have been shown to be reliable and highly accurate, with low inter-examiner and intra-examiner variability.[5,19-21] Nevertheless, logistics[22] and costs[21] generally limit their being accepted in routine clinical practice. Among many methods available for assessing ROM, visual estimation is the least reliable or accurate,[23] but it is the quickest and least expensive and is recommended in textbooks that describe the spinal-specific physical examination.[24] Despite the superiority of goniometers in measuring ROM, these significant barriers have limited their use in clinical practice. When assessing cervical spine ROM, most clinicians prefer visual estimates over goniometers.

We conducted a study to determine whether training could improve the accuracy of visual estimates. We compared the accuracy of visual estimates of cervical spine ROM with that of a radiographically validated electrogoniometer and then investigated whether accuracy and reliability of visual estimates could be improved with a session of instruction and demonstration. Assessments of accuracy were made immediately after and 1 month after this training session.

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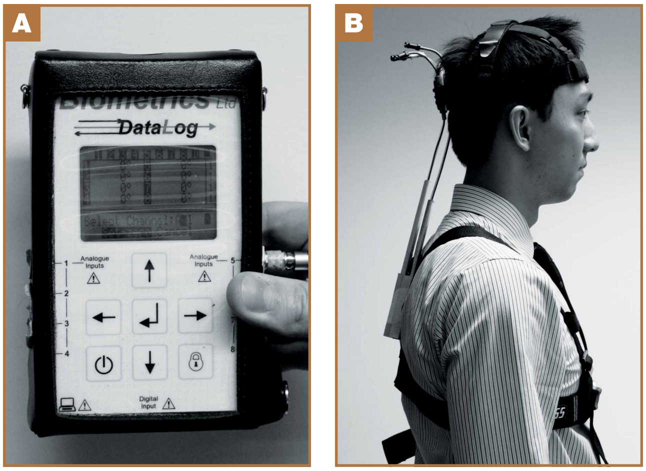

Figure 1. (A) Digital display of electrogoniometer. (B) Cervical harness of electrogoniometer fitted to subject in neutral position.

Figure 2. Subject, evaluator, and investigator (A) in neutral, (B) demonstrating extension, (C) demonstrating right lateral bending, and (D) demonstrating left rotation.

Materials and Methods

Assessments Made Before Training

This study was approved by our institution's human investigation committee and was conducted in accordance with the ethical standards of that committee.

Cervical spine ROM was assessed by 8 examiners (2 attending spine surgeons, 4 orthopedic residents, 2 medical students). They were informed they would be participating in a study evaluating visual estimates of motion but were given no other information prior to the study.

Four healthy volunteer subjects (examiners who rotated through the role) were assessed. No subject reported any ongoing neck or spine discomfort or had had any previous spinal surgery. One at a time, subjects were fitted with a cervical harness electrogoniometer capable of measuring angulation of the cervical spine to the nearest degree (modified electrogoniometer, torsiometer, and display from Biometrics, Gwent, UK; **Figures 1A, 1B**). This electrogoniometer has been shown to have a mean (SD) error of 2.3° (2.6°) relative to radiographic assessments.[8]

With the electrogoniometer fitted, each subject was instructed to sit upright in a chair with his back to the backrest and his head neutrally positioned. The electrogoniometer was then zeroed, and the subject proceeded with 5 series of flexion-extension, left and right lateral bending, and left and right rotation movements. The subject was instructed to make 1 movement in full motion in each direction and the other 4 movements in less than full motion to yield a variety of excursions for assessment. Each subject was instructed to pause at the apex of each motion. During these pauses, the examiners recorded their visual estimates of movement in each direction while the investigator recorded degrees of motion (displayed by the electrogoniometer) in flexion-extension, lateral bending, and rotation (**Figures 2A–2D**). The electrogoniometer display was not visible to subjects or examiners.

A total of 840 independent visual estimates of 120 distinct movements were recorded.

Training, and Assessments Made Immediately Thereafter

After the first round of visual estimates, the 8 examiners were verbally instructed in cervical spine ROM assessment and were asked to observe 1 subject, fitted with the electrogoniometer, demonstrating partial and full cervical motions while the investigator announced the electrogoniometric measurements. The motions demonstrated included 15°, 30°, and the extremes of cervical spine ROM in each of 6 directions from neutral.

After this training session, each of the 4 subjects from the first round of assessments was again fitted with the harness electrogoniometer and instructed to repeat the movements in turn while examiners visually estimated cervical spine ROM and independently recorded their estimates. Meanwhile, the investigator recorded the degree of motion during each movement (as measured by the electrogoniometer). Again, a total of 840 independent visual estimates of 120 distinct movements were recorded.

Assessments Made 1 Month After Training

One month after the training session, the examiners and the investigator reconvened to assess the same 4 subjects using a procedure for simultaneous visual estimation and electrogoniometric measurement identical to that used 1 month earlier. No additional training was given. Again, 840 independent visual estimates of 120 distinct movements were recorded.

Data Analysis

The reliabilities of visual estimates were analyzed by calculating the intraclass coefficients (ICCs) using random-effect 1-way analyses of variance. By convention, ICCs of < 0.2,

Table. **Mean Errors (ME) and 95% Confidence Intervals (CI) of Visual Estimation of Cervical Spine Range of Motion Before and After Training[a]**

	Flexion-Extension		Lateral Bending		Axial Rotation	
Timing Relative to Training	ME	95% CI	ME	95% CI	ME	95% CI
Before	23.9°	3.3°	15.5°	2.1°	19.3°	3.3°
Immediately after	12.0°	1.5°[b]	11.7°	1.7°[b]	16.4°	1.5°[b]
1 month after	14.4°	2.0°[b]	13.9°	2.0°	16.2°	2.5°

[a]n = 140. [b]$P < .05$.

0.2 to 0.39, 0.4 to 0.59, 0.6 to 0.8, and > 0.8 correspond to *poor, fair, moderate, substantial,* and *perfect* reliability, respectively.[25]

We compared the visual estimates and electrogoniometric measurements made for 3 planes of motion (flexion-extension, lateral bending, axial rotation) before, immediately after, and 1 month after training and drew trend lines generated by linear regression relative to a line of perfect correlation.

Mean errors in examiners' visual estimates (relative to electrogoniometric measurements) made before, immediately after, and 1 month after training were calculated. Paired Student *t* tests were then used to compare the mean errors before training with the mean errors immediately after and 1 month after training.

All analyses were performed with SPSS for Windows 16.0 (SPSS, Chicago, Illinois).

Results

Inter-examiner reliability of the visual estimates in all planes of motion ranged from 0.51 to 0.79 (suggestive of *moderate* to *substantial* reliability). For reference, standard goniometers measuring knee ROM have inter-examiner ICCs of 0.89 to 0.98[26] (suggestive of *perfect* reliability). The ICCs before, immediately after, and 1 month after training were not significantly different.

As expected, there were significant errors in visual estimates of cervical spine ROM in all planes. Initial errors in visual estimates (relative to electrogoniometric measurements) were 23.9° (flexion-extension), 15.5° (lateral bending), and 19.3° (axial rotation) (**Table, Figure 3**).

Immediately after training, mean errors in visual estimates decreased to 12.0° (flexion-extension), 11.7° (lateral bending), and 16.4° (axial rotation) (**Table, Figure 3**). In all 3 planes of cervical motion, these improvements were statistically significant.

One month after training, mean errors in visual estimates were 14.4° (flexion-extension), 13.9° (lateral bending), and 16.2° (axial rotation) (**Table, Figure 3**). Only the improvement in the estimate of flexion-extension (the direction of the largest error initially) remained statistically significant—a 39.7% decrease in error.

We also considered how errors varied with degree of motion observed. In flexion-extension, the tendency to overestimate at larger degrees of motion was not apparent after training, and 1 month after training we found a tendency to underestimate at smaller degrees of motion (**Figure 4A**). The tendency to overestimate lateral bending before training did not persist immediately after or 1 month after training (**Figure 4B**). Estimates of axial rotation correlated well with goniometer measurements before training and were also well correlated immediately after and 1 month after training (**Figure 4C**).

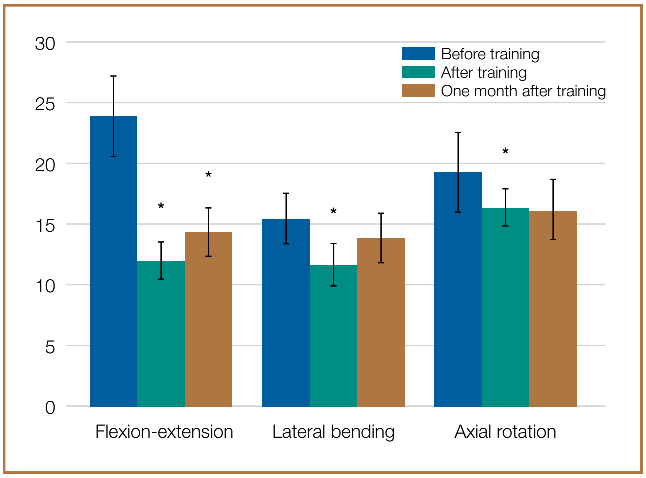

Figure 3. Mean errors in visual estimation of cervical spine range of motion in 3 planes before, immediately after, and 1 month after training. The y-axis represents mean absolute error in visual assessment of motion in flexion-extension, lateral bending, and axial rotation in degrees. The asterisks indicate statistically significant differences ($P < .05$) between mean errors immediately after or 1 month after training relative to mean errors before training. Error bars represent 95% confidence interval of mean errors (**Table**).

Discussion

Visual estimation of spinal motion is unreliable and inaccurate, but its widespread use in clinical practice continues. Goniometers are far more accurate and reliable but are seldom used. We investigated whether a training session featuring verbal instruction and demonstration with an electrogoniometer could improve visual estimates and whether potential improvement in visual estimates would remain 1 month after training.

Widely variable ICCs (0.42-0.90) have been reported for visual estimates of cervical spine ROM.[17,18,22] Our findings on the reliability of these estimates are consistent with the literature.

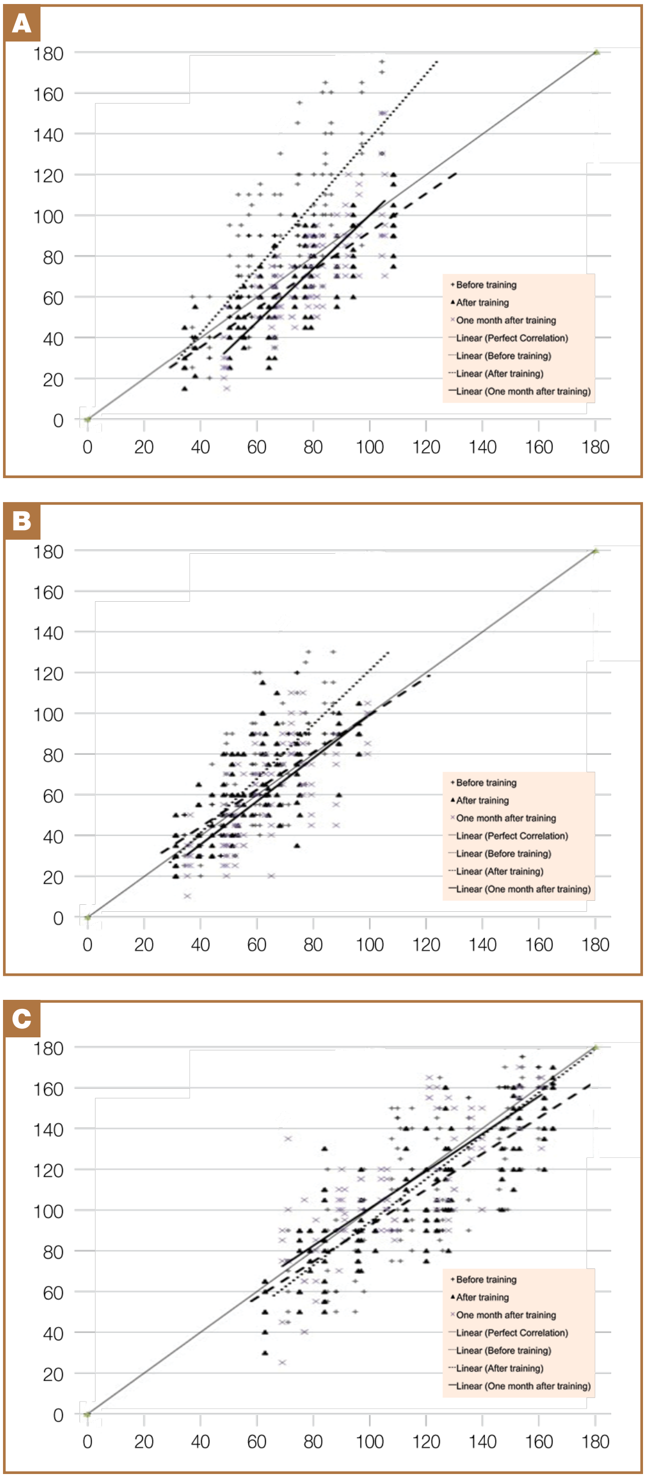

Figure 4. Scatter plots comparing examiners' estimations (y-axis) and electrogoniometer measurements (x-axis) of cervical spine range of motion in (A) flexion-extension, (B) lateral bending, and (C) axial rotation. Each of the examiners' 5 estimations in each direction were paired with a corresponding measurement of each subject's motion, yielding a scatter plot of estimations and measurements of motion in each of the 3 planes. The solid 45° line indicates perfect correlation between estimations and measurements. The trend lines generated by linear regression are displayed for data points recorded before, immediately after, and 1 month after training.

We recorded the greatest initial error in estimates of motion in flexion-extension. Previous studies have also found the greatest error and least reliability in visual estimates in this plane.[14,15,18] Visual estimation may be more difficult in flexion-extension because the shoulders cannot be used as landmarks, whereas they serve as approximate 90° reference points during estimation of lateral bending and axial rotation. Demonstration of 15°, 30° and the extremes of ROM during the training session may have provided alternative reference points during visual estimation after training—decreasing the error to within the range found in other planes of motion.

Initial errors in visual estimates were 23.9° (flexion-extension), 15.5° (lateral bending), and 19.3° (axial rotation). Based on normative cervical spine ROM in a healthy population—126° ± 12° for flexion-extension, 86° ± 5° for lateral bending, 151° ± 23° for axial rotation[22]—the errors we identified are 18.9% of the normal range of flexion-extension, 18.0% of lateral bending, and 12.8% of axial rotation.

Training clearly improved the accuracy of visual estimates of cervical spine ROM. Estimates were statistically improved for all planes immediately after training and remained significantly improved for flexion-extension (the plane of largest error initially) 1 month after training. Before training, mean errors varied across planes. Training normalized mean errors to about 15°, and this effect lasted in flexion-extension, lateral bending, and axial rotation (**Figures 4A–4C**). Of note, before training these percentage errors increased with increased motion from neutral in the flexion-extension and lateral bending planes. At full ROM, percentage errors in estimates were greater. After training, percentage errors did not increase appreciably with increasing motion.

Readers will naturally reflect on the clinical significance of the motion assessment improvements demonstrated after the training session described in this study. We must be aware that functional assessments are increasingly being emphasized in the clinical arena—with respect to clinical conditions, surgical outcomes, and functional impairments. We highlight a point made earlier: A difference of only 5° can affect impairment ratings in the medicolegal realm.[1] In estimating flexion-extension motion, lasting improvements of almost 10° were demonstrated and maintained 1 month after the training session described in this study.

Nevertheless, mean errors in visual estimation remained at about 15° in all planes of motion, despite our modest improvements. This finding raises the question of whether visually estimated ROM should be pertinent to assessments of impairment and disability. Although visual estimates of ROM may have more utility as a screening test for impairment and disability, fine differences in ROM simply cannot be reliably assessed by visual estimation.

This study has limitations. First, it was conducted at a single institution where the evaluators received most of their training. Their skill in visually estimating cervical spine ROM may not be generalizable to a larger population of spine specialists who are practicing at other institutions and may have different training backgrounds.

Second, only healthy subjects were assessed. Some studies of cervical spine ROM have shown better reliability in symptomatic subjects relative to asymptomatic subjects.[13,14] To attempt to overcome this limitation, we assessed many different excursions of motion that were often not to the extremes of motion.

Third, the "gold standard" we used for motion assessment was an electrogoniometer, which has some inherent error (previously validated mean [SD] error of 2.3° [2.6°] relative to radiographs[8]). Although obtaining radiographs of each movement would have more closely resembled the gold standard, the radiation dose associated with such a study is prohibitive.

Last, the assessors included medical students. The medical students' estimates, however, tended to be more accurate than the residents' or attending surgeons' (though the difference was not statistically significant). This tendency may reflect the medical students' closer attention to detail. Clearly, including medical students in the study did not negatively affect the accuracy of the estimates or the validity of our findings.

Conclusion

Despite its limitations, visual assessment of cervical spine motion remains the gold standard in clinical practice and is routinely recorded and reported. Mean errors ranged from 15.5° to 23.9°, depending on plane of motion being assessed, but these improved after a training session.

Visual estimates of motion in flexion-extension were most improved by training, as the initial errors in this plane were the largest. Statistically significant improvement of about 10° remained for flexion-extension motion estimates 1 month after training.

During a time when we are increasingly emphasizing functional outcomes, such a degree of improvement could be of clinical significance. Our study results support a call for more formalized training of ROM assessment, but clinicians should also be aware of the limitations of visual estimates of cervical spine ROM, and our study results support scrutiny of visual assessment of ROM as a criterion for diagnosing permanent impairment or disability.

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This paper will be judged for the Resident Writer's Award.