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A non-invasive technique for measurement of cervical vertebral angle: report of a preliminary study

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Abstract Non-invasive methods have traditionally been used to assess spine positioning and range of motion. Recently, the use of prediction models derived from external stick markers and videographic analysis has been shown to be effective at predicting lumbosacral and segmental lumbar vertebral angles. The objective of this study was to develop a similar non-invasive method to predict cervical vertebral inclination in forward head flexion. Fourteen subjects with no history of trauma or inflammatory or arthritic disorders (mean age: 25 ± 1 years) participated in this study on a voluntary basis. Radiographic and videographic measurements of four external markers (C0, C2, C6, C7) were taken for each subject at three different static head positions (neutral, and 30° and 60° of flexion). The data obtained from nine subjects with normal cervical configuration (lordosis) were used to develop statistical models predicting the radiographic segmental angles (dependent variables) from external markers (independent vari-

ables). A multiple regression model was developed for each vertebra (C1 to C6). These regression models predict the inclination of each cervical vertebra at three different neck angles with positional data derived from the four external skin markers. Adjusted R^2 values of 0.97, 0.93, 0.93, 0.96, 0.95 and 0.89 were obtained for C1, C2, C3, C4, C5 and C6, respectively. The prediction models developed in this study can explain a large part of the variance for the relative contribution of each vertebral segment to global neck flexion and provide a greater accuracy than using external stick markers only. These models were not able to adequately predict the vertebral angular positioning of subjects presenting a cervical alordosis or kyphosis.

Keywords Radiographic measurement · Videographic measurements · Cervical spine · Flexion · Segmental angle · External markers · Biomechanics

Introduction

Flexion of a normal cervical spine can be achieved only with the contribution of each cervical functional segment. Bogduk and Mercer [2] divided the cervical spine into four functional units: the atlas, the axis, the C2/C3 junction and the remaining four typical cervical vertebrae. Each of these

four units provides a unique contribution to the cervical flexion. While the head flexes, the occipital condyles roll forward and slide backward on their respective C1 articular surfaces. This combination of rolling and sliding allows, on average, 14° – 15° of flexion-extension. At full cervical flexion, the atlas can assume a flexed or an extended position, depending on whether the line of compression passes anterior or posterior to the contact point

of the atlanto-occipital joints. Radiographic studies have shown that the total flexion-extension of the atlanto-axial complex varies between 15° and 21°. Although the particular orientation of the articular surfaces between C2 and C3 makes the rotation at this segment different from that at the lower cervical segments, it does not seem to make any difference in the flexion pattern of movement [2, 18]. From C3 to C7, the superior anterior aspect of the vertebral body slopes downward and forward. This morphology reflects the major movement of the lower cervical spine: flexion-extension.

Many authors consider radiology to be the most accurate method to assess static positioning using bony landmarks [8]. Physicians and chiropractors use plain film radiographs to assess positioning of the spine, pelvis or even leg length discrepancy, as well as the functional status of the spine [5, 7, 9]. Dvorak et al. [5] performed functional radiographic analysis of the cervical spine and reported 10° of flexion-extension at C2-C3, 15° at C3-C4, 19° at C4-C5, 20° at C5-C6 and 19° at C6-C7. Other authors have tried to evaluate spine positioning and movement using an inclinometer, tape measurement, a standard cervical range of motion device, magnetic resonance imaging (MRI) or videographic analysis [1, 12]. Traditionally, range of motion parameters of the cervical spine were studied with a standard cervical range of motion device [14, 17]. Although it provides information on the implicit global function of the neck, it does not reveal what is actually happening at the segmental level. Clinically, segmental motion evaluation could be useful. Dvorak et al. [6] showed that segmental motion (rotation and translation of the lower cervical segments) is modified (hypomobility) in subjects suffering from degenerative changes and radicular syndrome.

For the lumbar spine, new non-invasive techniques to measure segmental vertebral inclination have been developed. Chen and Lee [3, 4, 11] showed that lumbar inclination estimated by prediction models derived from external stick markers and videographic analysis could be a good predictor of lumbosacral and segmental lumbar vertebral angles. Using linear and non-linear regression techniques they developed a model that could predict lumbar vertebral inclination using the torso angle (they reported R^2 values ranging from 0.91 to 0.97). For assessing spinal positioning and movement, non-invasive techniques (such as videographic analysis) have the merit of being less expensive and technically less difficult. Furthermore, these techniques do not expose individuals to X-ray radiation. This can be critical, particularly when the functional status of the spine has to be evaluated in pregnant women, or young or disabled populations.

The objective of this study was to determine whether a statistical model using a non-invasive technique (videographic analysis) can be used to predict cervical spinal positioning of the normal cervical spine. We also wanted to evaluate the accuracy of this particular model. To do so,

we compared lateral cervical spine radiograph measurements with those obtained from external stick markers placed on cervical spine and occipital bone. Development of this technique (different predictive models) may be helpful in monitoring the treatment of pathologic populations.

Materials and methods

Subjects

Nine subjects (three women, six men, mean age: 25±1 years, range 23–27 years) participated in this study. Subjects had no history of cervical trauma, bone pathology, or arthritic or other inflammatory disorders, and were asymptomatic at the time of the study. Five subjects (two women, three men, mean age: 25.6 years) with abnormal cervical curves (cervical alordosis or kyphosis) were also included in the study to determine the predictive properties of the model. The study design and consent forms were approved by the ethics committee of Laval University.

Radiographic measurements

Three lateral cervical spine radiographs were taken for each subject (neutral head position, 30° flexion, 60° flexion). Flexion of the cervical spine was determined using an inclinometer positioned on the head (neutral position=0°). Patient positioning was standardized by aligning the shoulders and thoracic spine with landmarks placed on the X-ray bucky tray. Subjects were instructed to maintain this posture throughout the evaluation. Neutral head position (0°) was determined by aligning the tragus and mid-axillary line and by instructing subjects to look at a fixed target located at eye level. On each film, vertebral inclination for C2 to C7 was defined as the angle between the line along the inferior plate of the vertebral body and the horizontal, obtained by a metallic horizontal level placed over the X-ray cassette. C1 inclination was defined as the angle determined by the line passing through the center of the anterior and posterior tubercle of the atlas and the horizontal line. Figure 1 illustrates the vertebral inclinations measured on X-ray films.

Videographic measurement

Simultaneous to each X-ray exposure, videographic sequences were recorded using a digital camera (JVC GR-DVL 9500, Japan). Videographic recordings were synchronized using a light-emitting diode (LED) lighting up simultaneously with the beginning of X-ray exposure. The camera was placed in the same plane as the X-ray tube, 1.22 m away from the radiographic film. Stick markers were used to document the relationship between external bony landmarks and cervical vertebral inclination as evaluated with X-rays. The stick markers were small wooden sticks (80 mm long and 5 mm diameter). Reflective tape was placed on each end of the sticks. The stick markers were then placed on the spinous processes of C2, C6 and C7 to externally represent the cervical spine. We used a lightweight helmet (123 g) to hold the C0 stick marker on the external occipital protuberance. The C0 stick marker was positioned to represent the angle formed by the line between the glabella and the external occipital protuberance. C2, C6 and C7 stick markers were directly placed on the skin over the spinous processes of the vertebrae using hypoallergenic double-faced tape. Figure 2 schematically presents the stick markers' positioning. After videographic recordings, the video sequences were captured on a computer with a movie editing software (Adobe Premiere 5.5 for PC). Ten consecutive images for each static position were selected.

Fig. 1 Vertebral inclinations measured on X-ray films. Vertebral inclination angles were measured between the horizontal line and a line passing along the inferior plate of each vertebra (C2–C6). C1 inclination was defined as the angle formed by line passing through the center of the anterior and posterior tubercle of the atlas and the horizontal line

Fig. 2 Markers positioning for videographic recording and analysis. Two reflective tapes (30 mm apart) were placed on each external wooden marker. External markers were placed over the C2, C6 and C7 spinous processes. The C0 external marker was fixed on a lightweight helmet, to represent the angle formed by the line between the glabella and the external occipital protuberance

These sequences of images (approximately 0.3 s, corresponding to the X-ray exposure time) were synchronized with the beginning of X-ray exposure. Digitization of the reflective tape placed over the stick markers was performed using a movement analysis software (APAS system, San Diego, USA). The angles formed by the two reflective tapes on each stick marker and the horizontal line were obtained for all subjects at each head position (neutral, 30°, 60° of flexion). These angles were used as independent variables to predict vertebral inclination measured on X-ray films (dependent variables).

Vertebral angle prediction models

For each cervical vertebra (excluding C7), a prediction model was developed using a forward stepwise multiple linear regression technique (Statistica 6.0, Tulsa, USA). These models were computed using data from the nine control subjects. Data from the remaining five subjects with abnormal cervical curves were used to assess the capacity of our models to adequately predict vertebral segmental positioning in patients with abnormal cervical spine configurations. Stepwise linear regression is a model-building technique which finds subsets of predictor variables that most adequately predict responses of a dependent variable, given the specified criteria for adequacy of model fit [13, 14, 15, 16]. Here, the model-building process determines the optimal combination of videographic angles to predict the radiographic angles. For example, to predict C1 vertebral inclination measured on X-ray film, the forward stepwise procedure first enters in the model the stick marker inclination (C0, C2, C6 or C7) that is best correlated with the radiographic angle of C1 (and significant in the model). For the subsequent steps, the stepwise process establishes whether adding a new variable increases the explained variance (or R^2); the variable is discarded if the explained variance does not increase significantly. The process stops when adding another independent variable does not increase the explained variance or when removing any included variable significantly decreases the predictive properties of the model. To be included in the model, the individual contribution of videographic angles had to be significant at $P < 0.05$ ($P > 0.10$ to be removed from the model if it was entered in a previous step). Assumptions of the regression models were evaluated using statistical indicators (tolerance and correlation matrix calculated with Statistica 6.0). As mentioned above, a regression model was developed for each cervical vertebra.

Results

Vertebral angles

Table 1 presents the mean vertebral angles (and standard deviation) measured from radiographs of the three head angular positions (subject with normal cervical configuration). The vertebral angles in neutral position ranged from 7.6° at C1 to 26.6° at C7. The C7 vertebral angle was measured in only 19 of the 27 radiographs due to X-ray under-penetration. As a result, the prediction models were only developed for the first six cervical vertebrae.

Stick marker angles were available for C0, C2 and C6. Values obtained for the nine subjects with a normal cervical configuration are presented in Table 2. For comparison purposes, angles measured from radiography for these three vertebrae are also presented (the C1 radiographic angle was compared with the C0 videographic angle). The

Table 1 Mean (SD) vertebral angles measured by radiography for the three head positions (in degrees)

Head position	C1	C2	C3	C4	C5	C6	C7
Neutral	-7.6 (7.0)	20.3 (6.4)	24.6 (7.9)	24.6 (5.7)	23.2 (3.1)	22.4 (5.5)	26.6 (6.4)
30°	22.8 (8.9)	43.6 (7.4)	44.5 (4.5)	39.8 (3.0)	32.9 (4.5)	28.3 (7.3)	31.1 (5.0)
60°	53.3 (7.2)	73.6 (5.5)	72.0 (4.1)	65.1 (4.9)	54.4 (5.0)	47.1 (6.0)	41.7 (10.7)

Table 2 Videographic angles (stick markers) and radiographic angles for three cervical segments

	Videographic angles (°)	Radiographic angles (°)	Error (°)
C0			
0°	-15.4 (5.5)	-7.6 (7.0) ^a	7.8
30°	12.0 (4.0)	22.8 (8.9) ^a	10.9
60°	39.3 (4.8)	53.3 (7.2) ^a	14.0
C2			
0°	-9.3 (10.1)	20.3 (6.4)	30.0
30°	12.3 (8.4)	43.6 (7.4)	31.3
60°	39.7 (7.3)	73.6 (5.5)	33.9
C6			
0°	31.0 (7.2)	22.4 (5.5)	8.5
30°	37.4 (5.4)	28.3 (7.3)	9.0
60°	55.5 (4.8)	47.1 (6.0)	8.4

^a Radiographic angle of C1 instead of C0

Table 3 Multiple regression model of C1 using angles of the C0 and C2 external skin markers (as measured from the digital images)

Var	C1		
	R	R ²	Adj R ²
C0	0.971	0.942	0.940
C2	0.985	0.970	0.968

errors obtained from the videographic measurement were important for all three vertebrae, and were greater than 30° for C2 (for all three head positions). Paired *t*-tests showed that differences were significant for all vertebrae ($P < 0.01$ for all comparisons). This clearly highlights the necessity of developing a predictive model.

Prediction models

The aim of the regression models is to predict the inclination of each cervical vertebra at three different head angular positions with position data derived from the four ex-

ternal skin markers. Table 3, Table 4 and Table 5 summarize the variables selected by forward stepwise linear regression and their respective R^2 and adjusted R^2 values. R^2 values are adjusted to take into account the number of observations as well as the number of dependent variables (i.e., videographic angles) used in the model. Adjusted R^2 values ranged from 0.885 for predicting C6 to 0.968 for predicting C1. Analysis of variance for each regression equation showed significant F values for all equations (F values ranging from 64.28 for C6 to 253.10 for C1, $P < 0.0001$ for all equations). All equations developed respected the fundamental assumptions of multiple regression analyses [18]. Post hoc power analysis for multiple linear regression was performed. Alpha was set to 0.01 and the R^2 value for the population was set at 0.86 for each model (the smallest R^2 value obtained). Finally, it was assumed that there were two independent variables per equation ($n=9$ subjects for all equations). With these premises, the smallest power of the linear regression calculated was 88%.

Table 6 presents the overall mean prediction errors, the standard deviations and the extreme prediction errors for each cervical vertebra. Prediction errors were calculated comparing the predicted vertebral angles (computed from the regression models previously developed) with the observed vertebral angles measured on X-ray films. They are presented for the normal subjects and subjects presenting cervical alordosis or kyphosis ($n=5$). These prediction errors were calculated for each subject (at all three cervical positions). For all vertebrae, mean and extreme prediction errors were more important for subjects with abnormal than those with normal spine configuration (with the exception of extreme prediction error in C3). Figure 3 illustrates the relationship between predicted and observed values for C2 (subjects with a normal spine configuration). The dashed lines represent the 95% confidence interval (CI). The dotted lines represent the 95%CI reported by Sigler and Howe [15] for interexaminer agreement in measuring cervical vertebral angles on plain radiographs (3.5°). Table 2 shows that simple stick marker an-

Table 4 Multiple regression model of C2–C5 using angles of the C0 and C6 external skin markers as measured from the digital images

Var	C2			C3			C4			C5		
	R	R ²	Adj R ²	R	R ²	Adj R ²	R	R ²	Adj R ²	R	R ²	Adj R ²
C0	0.963	0.928	0.925	0.953	0.908	0.904	0.955	0.911	0.908	0.943	0.888	0.884
C6	0.969	0.938	0.933	0.968	0.937	0.931	0.979	0.958	0.955	0.978	0.957	0.953

Table 5 Multiple regression model of C6 using angles of the C6 and C2 external skin markers as measured from the digital images

Var	C6		
	R	R ²	Adj R ²
C6	0.934	0.872	0.868
C2	0.945	0.893	0.885

Table 6 Mean (SD) prediction errors (in degrees) obtained from the regression models when compared with observed values on radiographs. Values for normal and abnormal cervical curves

	C1	C2	C3	C4	C5	C6
Normal configuration (n=9)						
Mean (SD)	3.8 (2.4)	4.5 (3.5)	4.4 (2.8)	2.8 (2.1)	2.2 (1.9)	2.8 (2.3)
Extreme prediction errors	8.3	10.8	10.5	6.6	9.3	8.6
Abnormal configuration (n=5)						
Mean (SD)	10.1 (8.5)	7.8 (5.6)	4.6 (3.0)	3.0 (2.5)	4.0 (3.6)	5.0 (3.2)
Extreme prediction errors	25.1	16.6	8.0	10.4	13.2	10.4

Fig. 3 Graph comparing the inclination angle predicted by the model (from videographic images) and the observed values as measured on the radiographs (C2 inclination). Each circle represents an observation. The dotted lines represent the confidence interval (95%) for interexaminer agreement in measuring cervical vertebral angles on radiographs (Sigler and Howe [15])

gle errors for all three head positions were greater than 30°. The extreme prediction error using our regression model is 10.8°, but the mean prediction error is only 4.5°. Thus, Fig. 3 shows that vertebral angles can be reliably predicted from a regression model derived from external stick markers. Extreme prediction errors are given to illustrate the worst case scenario.

Discussion

The purpose of this study was to determine whether statistical prediction models obtained from a non-invasive method could adequately estimate the segmental contribution of each cervical vertebra in forward neck flexion. We have developed prediction models that can explain a large part of the variance at each vertebral segment associated with neck flexion. These models account for 88.5–96.8% of the variance associated with segmental vertebral motion. All errors obtained from the regression models are smaller than those observed with a simple stick marker angle method. In fact, for most cases, the extreme prediction error is closer to radiographic measurement than the mean error obtained with the simple stick marker method. Interestingly, the C7 marker does not contribute to the prediction of any of the segmental vertebral inclination in the cervical spine.

This study was conducted to build prediction models that could be useful in evaluating the biomechanical status of the normal cervical spine (lordosis) and not to explain the cervical vertebral motion. The prediction models were developed from a young, asymptomatic population, and any clinical generalization to particular symptomatic populations would be beyond the scope of this paper. For the nine subjects with normal cervical lordosis, mean prediction errors calculated from the statistical models varied from 2.2° to 4.5°. Sigler and Howe [15] showed that interexaminer agreement in measuring cervical vertebral angles on radiographs reached 95% if the range of variance was 3.5°. Hence, statistical prediction models of vertebral cervical inclination seem to provide adequate estimations of vertebral inclinations and to be a promising tool to develop in the near future. The prediction errors, however, were higher (8.0°–25.1°) for the five subjects presenting cervical alordosis or kyphosis. This phenomenon was particularly important for the first and second cervical vertebrae, where most of the configuration changes occurred. This suggests that the initial position of the cervical spine (lordosis vs alordosis or kyphosis) is an important factor influencing the predictive quality of our models. It seems that, at this stage, our model can only be used for subjects presenting a normal cervical curve. Future developments of predictive models should include initial positioning of the cervical spine and skin movement modeling in order to provide adequate prediction of segmental positioning and motion in different asymptomatic and symptomatic populations.

Further studies are needed to explore the predictive properties of such models in different symptomatic populations: neck pain patients, whiplash patients, osteoarthritis patients, radicular pain patients, etc. This could also help identify particular biomechanical abnormalities experienced by those patients and guide them to appropriate therapy. Classical cervical range of motion (ROM) analysis focuses on total cervical ROM, whereas segmental cer-

vical ROM values are rarely examined in a clinical context. It could be useful to develop new prediction models derived from a more diversified asymptomatic population. Such predictive models could eventually be helpful in a clinical context to determine biomechanical dysfunction of the cervical spine. Moreover, clinical follow-up of symptomatic populations could be done more regularly, since this type of non-invasive evaluation limits exposure to ionizing radiation.

The present models focus only on a static analysis of a dynamic phenomenon. We do not have any radiographic data concerning what happened in the cervical spine between two different head positions. Future developments using videofluoroscopy and MRI could lead to modeling of cervical segmental motion in flexion, extension, rotation and lateral bending. This could help to evaluate segmental kinematic factors that are identifiable neither on static images nor on X-rays. Such developments could be very useful to evaluate cervical postures and motion in ergonomic studies as well as in motor control studies. Development of new external markers to evaluate trunk and shoulder movements could improve R^2 and predicted values for forward head flexion. Such markers could help in the prediction of vertebral inclination in more functional

tasks where the trunk and upper thoracic spine is moving. Finally modeling of the skin and soft tissue movements under the stick marker could also allow more precise predictions of vertebral inclinations.

Conclusion

The results of this study support the use of external stick markers and associated prediction models to provide evaluation of segmental vertebral angulation of the cervical spine. Further studies are needed to validate the models in different symptomatic and asymptomatic populations. The use of videofluoroscopy and MRI could be a future path of investigation [10]. Extension, rotation and lateral flexion motion should also be studied with non-invasive techniques in order to develop new predictive models of segmental spinal motions.

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References

1. ACSM (1998) ACSM's resource manual for guidelines for exercise testing and prescription, 3rd edn. Williams and Wilkins, Baltimore, pp 371–372
2. Bogduk N, Mercer S (2000) Biomechanics of the cervical spine. I. Normal kinematics. *Clin Biomech* 15:633–648
3. Chen YL (2000) Predicting the vertebral inclination of the lumbar spine. *Ergonomics* 43:744–751
4. Chen YL, Lee YH (1997) A non-invasive protocol for the determination of lumbo-sacral vertebral angle. *Clin Biomech* 12:185–189
5. Dvorak J, Froehlich D, Penning L, Baumgartner H, Panjabi MM (1988) Functional radiographic diagnosis of the cervical spine: flexion/extension. *Spine* 13:748–755
6. Dvorak J, Panjabi MM, Grob D, Novotny JE, Antinnes JA (1993) Clinical validation of functional flexion/extension radiographs of the cervical spine. *Spine* 18:120–127
7. Fann AV, Remington L, Verbois GL (1999) The reliability of postural x-rays in measuring pelvic obliquity. *Arch Phys Med Rehabil* 80:458–461
8. Gilliam J, Brunt D, MacMillan M, Kinard RE, Montgomery WJ (1994) Relationship of the pelvic angle to the sacral angle: measurement of clinical reliability and validity. *J Orthop Sports Phys Ther* 20:193–199
9. Jackson RP, Kanemura T, Kawakami N, Hales C (2000) Lumbopelvic lordosis and pelvic balance on repeated standing lateral radiographs of adult volunteers and untreated patients with constant low back pain. *Spine* 25:575–586
10. Karhu JO, Parkkola RK, Komu ME, Korman MJ, Koskinen SK (1999) Kinematic magnetic resonance imaging of the upper cervical spine using a novel positioning device. *Spine* 24:2046–2056
11. Lee YH, Chen YL (2000) Regressionally determined vertebral inclination angles of the lumbar spine in static lifts. *Clin Biomech* 15:672–677
12. Loudon JK, Ruhl M, Field E (1997) Ability to reproduce head position after whiplash injury. *Spine* 22:865–868
13. Neter J, Wasserman W, Nachtsheim, Kutner MH (1996) Applied linear regression models, 3rd edn. Irwin, Chicago
14. Ordway NR, Seymour R, Donelson RG, Hojnowski L, Lee E, Edwards WT (1997) Cervical sagittal range-of-motion. Analysis using three methods. *Spine* 22:501–508
15. Sigler D, Howe J (1985) Intra and inter-examiner reliability of the upper cervical X-ray marking system. *J Manipulative Physiol Ther* 9:75–80
16. *Statistica for windows* (2001) Version 6.0. Statsoft, Tulsa
17. Tucci SM, Hicks JE, Gross EG, Campbell W, Danoff J (1986) Cervical motion assessment: a new, simple, and accurate method. *Arch Phys Med Rehabil* 67:225–230
18. Yoganandan N, Kumaresan S, Pintar FA (2001) Biomechanics of the cervical spine. 2. Cervical spine soft tissue responses and biomechanical modeling. *Clin Biomech* 16:1–27