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I. Ait Oumghar, A. Barkaoui & P. Chabrand

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Using external back shape curvature to predict internal vertebrae positions in sitting postures: preliminary results

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1. Introduction

Predicting vertebrae positions in different spinal postures from external data, using a single regression for each vertebra, could be interesting for clinical and ergonomics applications by limiting the exposure to radiation. With a limited set of markers, Nerot et al (2018) achieved one of the best predictions with a geometrical method, reaching an average error of 10.2 ± 5.6 mm between the predicted position of intervertebral joint centres and their actual position on radiographs for C7-T1 to L5-S1 intervertebral joints. The prediction model was specific to a free-standing posture.

The aim of our study was to build models which are valid and robust in several seated spinal postures. To achieve this goal, predictors that are correlated to spinal postures should be added to existing models. We hypothesized that external back shape curvatures are important predictors of vertebrae positions. As a first step to assess this hypothesis, univariate statistical models were built; only the best coefficients of determination (R^2) of models from C4 to Th10 vertebrae were considered and presented in these preliminary results.

2. Methods

2.1. Data collection

Twenty-one healthy participants (13 females, 23.6 ± 4.4 years, BMI 21.9 ± 1.5 kg/m²) were recruited after ethical endorsement (CPP N°2020-A00573-36). Cutaneous markers were positioned facing C4 to T10 spinous processes, by manual palpation. Low dose radiographs (EOS® Imaging, France) were taken in 3 postures: slouched, erect and the usual sitting posture of the participants (called reference).

Superior-posterior vertebral corner (Klinich et al. 2012) and cutaneous markers coordinates were extracted using a Matlab toolbox (Gasparutto and Tomezzoli 2021).

Furthermore, to quantify the magnitude of the differences between spinal postures, the C2-C7 cervical lordosis and T1-T12 thoracic kyphosis angles were measured using the 2D tool SterEOS® (EOS® imaging, Paris, France).

2.2. Building of the curvilinear frames

To represent the back shape, external markers were fitted using the cubic spline function *csaps* of Matlab (The MathWorks I 2021). The smoothing parameter value $p = 10^{-4}$ was chosen based on graphical criteria, to reach a compromise between smoothness and proximity to external markers at the thoracic level. At the cervical level, a more flexible spline was needed; this is consistent with the literature, as the intervertebral range of motion is higher at the cervical spine than at the thoracic spine levels (White and Panjabi 1990). Consequently, C4 to C6 markers were weighted more than T2 to T10 markers (weights $w = 32$ versus 1), C7 and T1 being weighted with intermediate values to ensure continuity.

The spline was discretized into approximately 30 000 points equally distributed along their absolute vertical coordinate. The resulting distances between two consecutive spline points never exceeded 0.02 mm. The external markers were then projected perpendicularly on the spline (P points). Tangents and normals were computed to build curvilinear Frenet frames at each P point. All normals were then orientated forward in relation to the participant (Figure 1).

2.3. Variables and statistics

The distance (d) between each P point and its vertebral upper-posterior corner counterpart was computed, along with the angle (α) between this segment and the spline normal. Furthermore, at each P point, the spline curvature (k) was calculated as a derivative of the tangential vector with respect to the curvilinear distance, with a negative sign if its direction was opposite to the normal vector direction (i.e. for lordosis).

The statistical significance of the effect of posture on C2-C7 angles, T1-T12 angles and spine curvatures was assessed using linear models (R Core Team 2018). The statistical links between external curvatures and distance d and angle α were computed at each P point, using univariate linear models. After visually checking for model residuals' normality, the model yielding the best R^2 for each vertebra was reported.

3. Results and discussion

3.1. Descriptive statistics

The C2-C7 angle was $15.3^\circ \pm 10^\circ$, $25.3^\circ \pm 10.1^\circ$ and $40.7^\circ \pm 13.8^\circ$ in the erect, reference and slouched

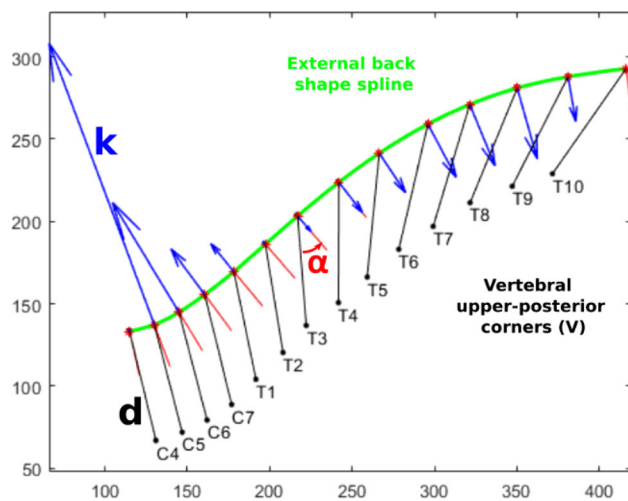


Figure 1. Back parameters. Red points: projection of cutaneous markers on the spline (P). Red lines: normal vectors directions (N). Blue arrows: spline curvatures (k), α : angle (PV , N), d : distance [PV].

postures, respectively; the T1-T12 angle was $28.7^\circ \pm 9.1^\circ$, $37.5^\circ \pm 11.2^\circ$ and $54.3^\circ \pm 12.4^\circ$ in those postures, a negative sign indicating a kyphosis. Mean curvatures (k) ranged from -0.0181 mm^{-1} at C6 to 0.0033 mm^{-1} at T7 level. Mean angles (α) ranged from -0.1° at the C4 vertebra level to 40.7° at T10. Mean distances (d) ranged from 61.1mm at C5 to 75.4mm at T10 level.

Postures were distinctive to each other in terms of C2-C7 angles ($p < 0.001$), T1-T12 angles ($p < 0.001$) and spline curvature in C4 ($p < 0.01$), C5 ($p < 0.001$), C6 ($p < 0.01$), T1 ($p < 0.01$), T2 ($p < 0.05$), T5 ($p < 0.01$) and T6 to T10 ($p < 0.001$).

3.2. Predictive ability of spline curvatures

Maximal R^2 of models for angles (α) prediction ranged from 0.21 to 0.61 ($p < 0.001$). They were mostly associated with spline curvatures located around C7 (Table 1). Maximal R^2 for distances ranged from 0.17 to 0.31 ($p < 0.001$), associated with spline curvatures located around C7 and from T6 to T10.

4. Conclusions

To assess the relevance of using back shape curvatures as predictors of vertebrae positions in various spinal postures, statistical links between vertebrae positions, expressed in local curvilinear frames, and local back shape curvatures were computed. Coefficients of determination of a model usually increase along with the number of variables included in the model. The models built by Nerot et al (2018) included 1 to 4 variables and had R^2 ranging from 0.4 to 0.8,

Table 1. Best predictors, among spline curvatures, for distance d and angle α .

Vertebrae	Best predictors for	
	Angle α (R^2)	Distance d (R^2)
C4	kC6 (0.53)	kC6 (0.29)
C5	kC7 (0.48)	kT6-kT7 (0.30)
C6	kC6 (0.46)	kT6 (0.31)
C7	kC7 (0.61)	kT6 (0.19)
T1	kC7 (0.33)	kT1 (0.17)
T2	kt5 (0.26)	kC7 (0.21)
T3	kt5 (0.35)	kC7 (0.22)
T4	kC7 (0.30)	kC7 (0.27)
T5	kC7 (0.24)	kt10 (0.23)
T6	kC7 (0.22)	kt10 (0.25)
T7	kt1 (0.24)	kt9 (0.24)
T8	kt1 (0.32)	kt9 (0.26)
T9	kt1 (0.33)	kt8-kt10 (0.25)
T10	kt1 (0.21)	kt8, kt10 (0.22)

depending on the vertebral joint level. The order of magnitude of R^2 in our study seem therefore high enough to consider the back shape curvature as an additional potential predictor of vertebrae positions; as curvatures are related to spinal posture, this parameter could help build models which are valid in several spinal postures. This should allow improving subject specific manikins and might help monitoring the risk of vertebrae fractures in osteoporotic patients. To further this preliminary analysis, multivariate regressions that include usual predictors, e.g. related to participants' anthropometry might be built and a validation analysis conducted.

Disclosure statement

No potential conflict of interest was reported by the authors.

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