PREDICTION OF LUMBAR SPINE POSTURE FOR REPOSITIONING OF SPINAL FE MODEL

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ABSTRACT

A technique to reposition the spinal column in FE HBM's based on the trunk flexion or pelvis rotation angle is presented in the study. Representation of the spinal posture using natural splines is found to be an effective way of locating the position and orientation of the vertebrae when the spinal column is being flexed. Cobb and inter segmental angles obtained are in agreement to those reported in literature. It is also indicated that in clinical studies, a simplified analysis of radiographs is possible by interpreting the position of only five key vertebrae.

Keywords: SPINE, HUMAN BODY, FINITE ELEMENT

HUMAN BODY FE MODELS (FE-HBM) are being developed to investigate injuries due to impact. Injury levels due to airbag deployment, in out of position (OOP) upper extremity, are reported to vary with position change (Ono et al., 1998, Prasad et al., 1997, Strother et al., 1994). The recommended car occupant positions for both standard and OOP analysis are indicated in safety standards. With respect to the car occupant’s upper extremity, most of the situations of interest in the safety standards are obtained by movement of the spine in the sagittal plane.

Commercially available FE-HBMs are in a few standard postures. Repositioned models are needed to be obtained for OOP simulations. Several attempts are reported in literature to obtain non standard postures from available standard postures. Dynamic simulation method for mesh modification of lower extremity is reported by Chawla et al., (2004). They report that the simulation time is very long and requires a large number of iterations and user interventions. Similar issues are also expected while repositioning upper extremity models. A faster method thus needs to be developed for changing the posture of existing FE-HBM's upper extremity without compromising their biofidelity or computational efficiency. Postural change in the upper extremity consists of two steps, viz, repositioning of spinal vertebra followed by repositioning of the soft tissue mesh associated with the spine. The current paper addresses the first step, repositioning of spinal vertebra in the sagittal plane.

CLINICAL LITERATURE: Intricacy in measurement and prediction of the inter-vertebral movements of the lumbar spine has been reported in clinical literature. Difficulties arise as the spine is rather inaccessible, and the nature of the movements is complex (Sun et al., 2004). Measurement of intervertebral lumbar movement is through radiographic images for flexion and extension postures along with movement information derived from rotational movement of marker triads taped to the skin. The clinical interest is to *analyze* and quantify the inter-vertebral motion. Ma et al., (2008) for example make use of Bayesian network dynamic model to determine intervertebral kinematics for the lumbar spine. Sun et al., (2004) developed an inverse kinematic model for determining inter-vertebral joint motion.

In FE model repositioning, a spine construction is available in one posture. The problem is to generate another or a series of accurate spine postures which are anatomically consistent given the externally measureable parameters, sternum angle, thorax angle and pelvis angle. These angles can also be associated with the geometry of the seat and headrest complex.

METHOD

NATURAL SPLINE TECNHIQUE: In the current study inter vertebral positions have been predicted by cubic interpolations between the positions of key vertebrae in one given posture. Change in lumbar posture due to the sagittal movement of thorax can be predicted with the proposed method.

The proposed method can be used in FE HBM repositioning as it does not require information from other postures.

The cubic spline is used extensively in computer graphics to draw a smooth line passing through given number of points. The algorithm for natural spline technique using cubic interpolation is presented below in pseudo code. Given a function f on $[a, b]$ and nodes $a = x_0 << x_n = b$, a cubic spline interpolant S for f satisfies:

(a) $S(x)$ is a cubic polynomial $S_j(x)$ on $[x_j, x_{j+1}]$

(b) $S_j(x_j) = f(x_j)$ and $S_j(x_{j+1}) = f(x_{j+1})$

(c) $S_{j+1}(x_{j+1}) = S_j(x_{j+1})$ …. *(position)*

(d) $S'_{j+1}(x_{j+1}) = S'_j(x_{j+1})$….*(first derivative: Slope)*

(e) $S''_{j+1}(x_{j+1}) = S''_j(x_{j+1})$….*(second derivative: Curvature)*

(f) One of the following boundary conditions:

(i) $S''(x_0) = S''(x_n) = 0$ (*free or natural boundary: Used in the method*)

METHODOLOGY: AM50 model has been used in the study as it represents a fairly large population of the clinical studies as well as available FE models. In the proposed method, the FE mesh of the spine in the, AM50 model was used to locate the vertebral corners. Subsequently, six global and seventeen segmental angles are computed from the FE mesh using the cubic spline interpolation. Methods quantifying lordosis summarized by Harrison et al., (2001) were used to validate the accuracy of proposed method. In radiographic evaluation of lumbar lordosis, Cobb, centroid, TRALL and posterior tangent method are usually adopted. Lumbar lordosis was defined by the angle of intersection between a line running along the inferior border of T12 and a line along the superior border of the sacrum. Clinically, this is referred to as Cobb’s method and is readily determined from the FE mesh of the lumbar vertebra. Cobb and centroid lumbar lordosis (CLL) angles were used to evaluate the performance of the cubic spline interpolation used.

Standing posture of spine was assumed to be contained in the saggital plane without any lateral excursions (Pearcy, 1985) and orientations of the vertebrae were represented by tangents or first derivatives. Four vertebrae (T1, T6, L5, and L1) are located given the sternum angle, thorax angle and pelvis angle with the additional assumption that the thoracic portion of the spine is rigid. These vertebrae are used as key vertebra or knots for spline fitting. The remaining vertebrae are located by fitting.

VALIDATION METHODOLOGY: Two points of validation are considered. First if the positions of the vertebrae located through spline fitting is consistent with reported anatomical data in the standing posture. Secondly to check if the known changes due to extension of the neck including transition from lordosis to kyphosis is reproduced.

Figure 1(a) collates Cobb angle and its standard deviation for erect posture. Figure 1(b) collates the intersegment angles in the lumbar vertebra positions. Additional (OOP) spinal postures from clinical literature [Chen (1999) and Enis et al., (2009)] are used to check the response in extension of the neck.

RESULTS

ERECT POSTURE: Location of key vertebrae was used to compute the position and orientation of intermediate vertebrae of the lumbar spine using the natural spline technique. This orientation was then compared with that in reported literature for healthy subjects (Figure 1 (a)). It is observed that the lumbar lordosis (Cobb angle) calculated by the natural spline technique is 52.13^o, while that in clinical studies is $53.53^o \pm 12.9^o$. It is also observed from Figure 1(b) that the segmental contributions to lumbar lordosis predicated by the spline method in the upright posture are -4.39^o for L1-L2, -6.41^o for L2-L3, -11.48^o for L3-L4, -19.97^o for L4-L5 and -9.075^o for L5-S1. The mean error in the intersegmental angles is less than 0.8^o. We thus conclude that the natural spline technique well predicts the positions and orientations of lumbar vertebrae.

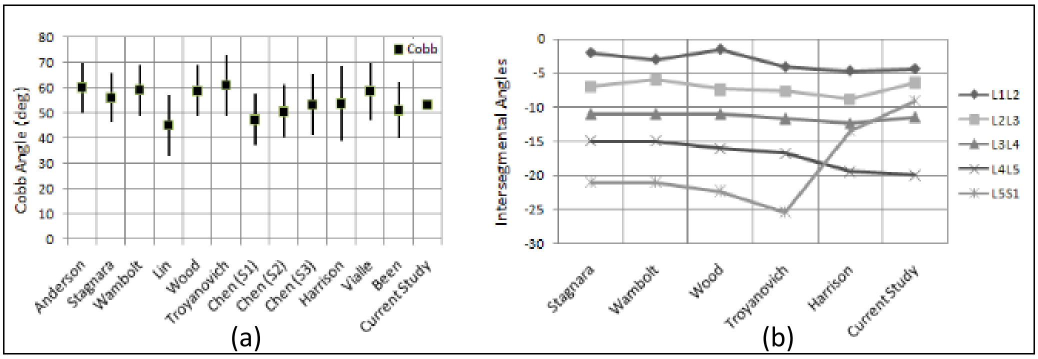

Fig. 1 (a) Summary of reported Cobb angle in literature. (b) Summary of reported intersegmental angles in lumbar spine. (Collated from Anderson et al., 1979, Stagnara et al., 1982, Wambolt et al., 1987, Lin et al., 1992, Wood et al., 1996, Troyanovich et al., 1997, Chen 1999, Harrison et al. 2001, Vialle et al., 2005, Been et al., 2007)

POSTURE IN FLEXION: Flexed posture of the upper extremity was achieved by the sagittal movement of thorax about the lumbo-sacral joint. Natural spline technique was used to predict the position and orientations of the lumbar vertebrae in the flexed posture. Movement sequence of the spine in flexion was determined for positions corresponding to that in Chen (1999). Figure 2(a) shows spine flexion simulated for forward bending for two different trunk angles, 30^o and 60^o. The bony structure of the upper extremity as well as the spine position obtained for a 30^o flexion is shown in Figure 2(b).

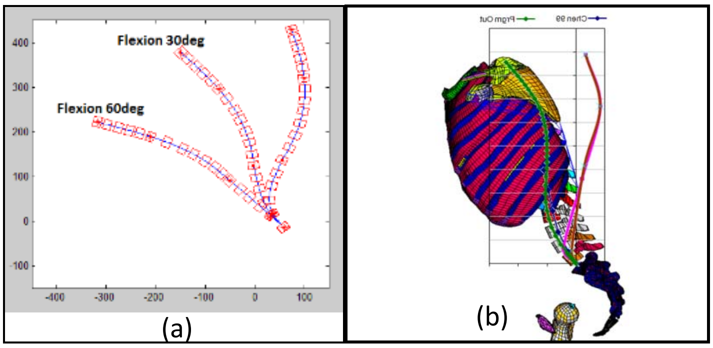

Fig. 2 (a) Computed spline flexion in erect, 30^o and 60^o. (b) 30^o flexion with other structures.

Chen (1999) reported that for 30^o trunk flexion the Cobb angle for L1-L5 is $32^o \pm 1^o$ while the spline interpolated value is 33.68^o. For trunk flexion of 60^o the Cobb angle for L1-L5 is 10.0 ± 1^o while the spline interpolated value is 8.98^o with the shape of spine changing from lordosis to kyphosis. Likewise the mean error observed in the intersegmental angles is less than 1.8^o in comparison to the data reported by Enis et al., 2009. Table 1 summarizes and compares the reported data with that predicated by the proposed method.

Table 1. Comparison of intersegmental angles

	L1-L2	L2-L3	L3-L4	L4-L5	L5-S1
Enis et al	30.0^o	26.3^o	20.4^o	12.9^o	6.5^o
Calculated	29.3^o	24.5^o	19.2^o	12.2^o	6.1^o
Error	0.7^o	1.8^o	1.1^o	0.7^o	0.4^o

It is interesting to note that the change of lordosis to kyphosis is observed during flexion. Similar phenomena are also reported in clinical literature (Anderson et al., 1979, Chen 1999, Ma et al., 2008). This further establishes the accuracy of the proposed method.

DISCUSSION

The paper presents a new method for regenerating the spine model for OOP situations without either using dynamic simulations or a stored database of many configurations. The proposed technique has been incorporated in a program which takes as an input the initial posture of spine and angle of thorax flexion/extension and outputs the new spinal posture. The reliability of method is demonstrated for sagittal motions of the lumbar spine by comparing with data reported in clinical literature. Due to its ease of applicability, the methodology can also be used to predict postural changes in clinical application for spine without deformity. It is assumed that in the current study no relative motion of thoracic vertebra is allowed. The current work only deals with repositioning of the lumbar spine vertebrae. Repositioning of soft tissues and ligaments associated with the spine are being addressed and would be reported in the future.

CONCLUSION

The problem of generating anatomically consistent, unloaded, spinal configurations of a FE-HBM has been addressed. Computation of inter-vertebral movement for an FE-HBM lumbar spine is comparable to the spread reported in experimental data. Results indicate that repositioning of the spinal vertebra in FE-HBM can be done accurately and quickly without resorting to interpolations between known positions or dynamic FE simulation.

FUTURE WORK

The methodology can be extended to predict postural changes in spine with change in hip position. As the proposed method is fast and accurate, it can hopefully also be extended to clinical applications involving radiography. The method is also to be extended to include the ribcage and associated structure of the thorax along with the associated soft tissues in spine.

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