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Short communication

Technique for chestband contour shape-mapping in lateral impact

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ABSTRACT

The chestband transducer permits noninvasive measurement of transverse plane biomechanical response during blunt thorax impact. Although experiments may reveal complex two-dimensional (2D) deformation response to boundary conditions, biomechanical studies have heretofore employed only uniaxial chestband contour quantifying measurements. The present study described and evaluated an algorithm by which source subject-specific contour data may be systematically mapped to a target generalized anthropometry for computational studies of biomechanical response or anthropomorphic test dummy development. Algorithm performance was evaluated using chestband contour datasets from two rigid lateral impact boundary conditions: Flat wall and anterior-oblique wall. Comparing source and target anthropometry contours, peak deflections and deformation-time traces deviated by less than 4%. These results suggest that the algorithm is appropriate for 2D deformation response to lateral impact boundary conditions.

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1. Introduction

In biomechanical postmortem human subject (PMHS) experiments, the chestband device has permitted measurements of torso deformations throughout impact without invasive instrumentation or parallax error from videographic analysis (Eppinger, 1989). Validated for lateral sled impact experiments using an anthropomorphic test dummy (Pintar et al., 1996), subject-specific chestband contour shapes were post-processed to quantify deflection responses to impact (Kuppa et al., 2003; Pintar et al., 1997; Shaw et al., 2006; Yoganandan et al., 2008). Methodologies by which chest deflections were quantified from the contours have been varied (Fig. 1). For example, deflections were considered to be the maximum change in distance between the spine–sternum axis and three select circumferential points (Pintar et al., 1997), between any two contour location pairings (Shaw et al., 2006), or between the impacted contour aspect and a fixed point on the spine–sternum axis (Yoganandan et al., 2008). Yet, in each methodology the resulting uniaxial deflection responses may neglect potentially injurious deformations remote from the metric computation site, e.g., narrow-object intrusion in motor vehicle side impact crashes (Pintar et al., 2007). Multidirectional deformation patterns may pose unique injury mechanisms and require multipoint response characterization. Such complex deformations also may be suitable for examination through viscoelastic finite element (FE) methods to characterize visceral response.

Deformations as characterized by chestband contours may be applied to computational models to reproduce subject visceral response. Yet because contours are subject-specific, subject-specific models would be required. Prior human biomechanical FE models for injury evaluation, e.g., HUMOS (Behr et al., 2003), were developed using standard anthropometry measurements and required extensive mesh optimization. Model complexity therefore may prohibit adapting model geometry to experimental test subject anthropometry. Consequently, the present study developed an approach by which subject-specific chestband contours were adapted (mapped) to a standardized anthropometry cross-section for computational examination.

2. Methods

All data were pre-processed using the RBandPC software (ver. 3.0, Conrad Technologies, Inc., Washington DC, available from the U.S. Department of Transportation) accompanying the chestband transducer (Denton Inc., Farmington Hills, Michigan). Briefly, ASCII chestband data were generated consisting of closed contours for each sample time t. Each contour consisted of i points in approximately 2 mm intervals; each point was expressed within a Cartesian coordinate system defined by user-specified spine and sternum locations (Fig. 2). Origin (O) was defined by the spine. For each contour point i, clockwise circumferential distance (s_i) and Cartesian vector coordinates ($\mathbf{R_i}$) were quantified with respect to O.

2.1. Algorithm

The mapping algorithm was developed using MATLAB (MathWorks, Natick, MA). ASCII data were imported from a source chestband contour for all t, and the spine

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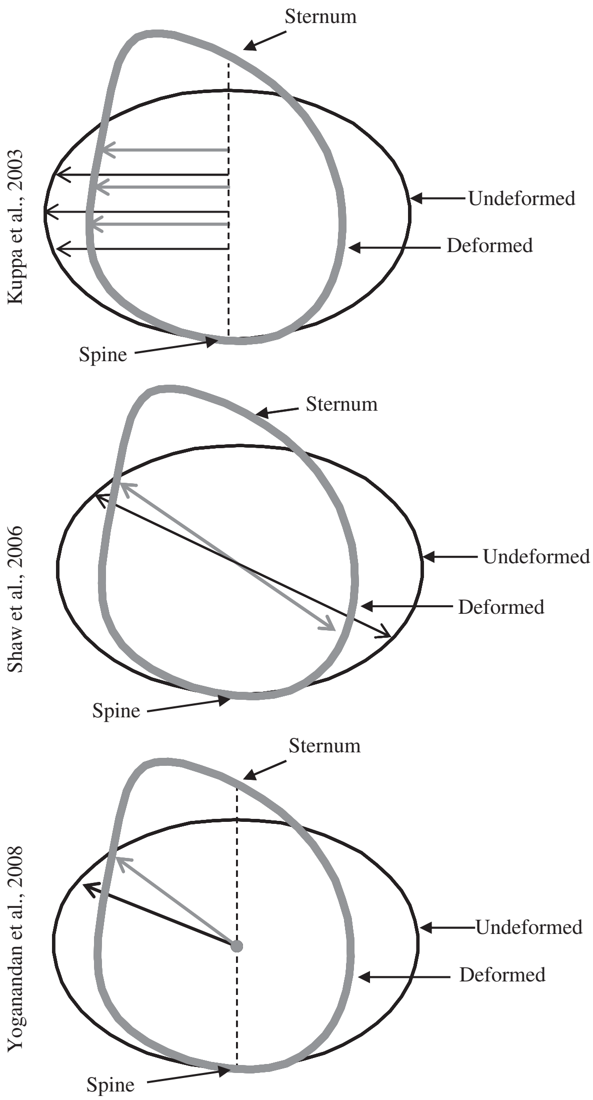

Fig. 1. Deflection calculation methods for chestband contours from PMHS lateral impacts.

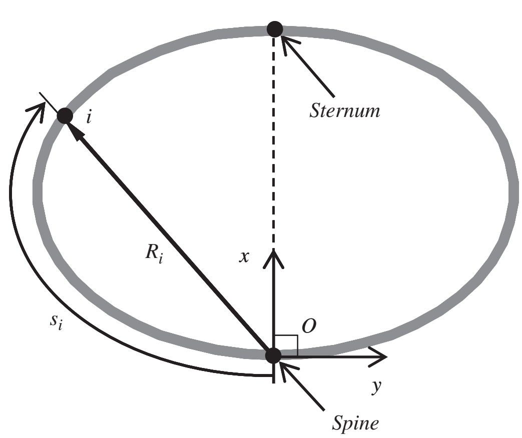

Fig. 2. Contour data generated by RBandPC for contour point i.

and sternum locations were maintained. Two vectors **X** and **Y** were defined according to Eqs. (1) and (2) with respect to: spine centerline (O), sternum centerline ($\mathbf{R_A}$), and points equal to half the circumferential distance between spine and sternum on the left ($\mathbf{R_L}$) and right ($\mathbf{R_R}$) sides (Fig. 3)

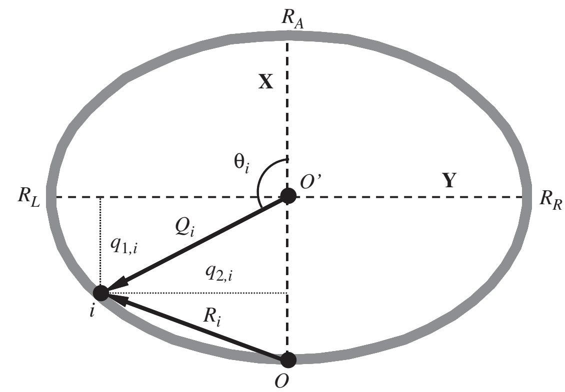

Fig. 3. Contour axes definition used to obtain q_1 and q_2 with respect to **X** and **Y**.

$$\mathbf{X} = \mathbf{R_A} - O = \mathbf{R_A} \tag{1}$$

$$\mathbf{Y} = \mathbf{R_R} - \mathbf{R_L} \tag{2}$$

A new origin (O') was defined by the intersection of **X** and **Y**. Vector $\mathbf{Q_i}$ then defined the location of contour point i with respect to O'. Arbitrary coordinates q_1 and q_2, defined according to Eqs. (3) and (4), expressed point i with respect to the axes defined by **X** and **Y**

$$q_{1,i} = \mathbf{Q_i} \cdot \mathbf{X} \tag{3}$$

$$q_{2,i} = \mathbf{Q_i} \cdot \mathbf{Y} \tag{4}$$

Parameters $q_{1,i}$ and $q_{2,i}$ represented a new spatial definition for point i. These parameters were then expressed with respect to contour circumference s, generating two uniaxial functions to describe the overall shape of the contour (Fig. 4a). Yet, each contour circumference was subject-specific with the sternum falling at a unique distance from the spine. Therefore a normalized contour circumference was defined with respect to the spine ($s'_P=0$), sternum ($s'_A=0.5$), total circumference ($s'=1.0$), and the half-distance between spine and sternum on the left ($s'_L=0.25$) and right ($s'_R=0.75$) side (Fig. 4b). Recall that the sets q_1 and q_2 represent the band shape at a specific sample time t. The shape change over the entire time duration was considered by normalizing each set of q_1 and q_2 with respect to q_1 and q_2 values at $t=0$ (Eqs. (5) and (6)). Final normalized datasets consisted of dimensionless u_1 and u_2 coordinates, unique for each sample time, with respect to dimensionless circumference s' (Fig. 4c)

$$u_1 = \frac{q_{1,t=t_1}}{q_{1,t=0}} \tag{5}$$

$$u_2 = \frac{q_{2,t=t_1}}{q_{2,t=0}} \tag{6}$$

These dimensionless datasets permit source contour deformations to be mapped to a target geometry with unique initial dimensions and n discrete contour points. This was accomplished by first repeating for the target geometry the computational process to obtain undeformed $q_{1,n}$ and $q_{2,n}$ with respect to s'_n (Fig. 4b). This corresponded to $t=0$ for the target geometry. The MATLAB 'interp1' function was employed to interpolate using cubic splines the normalized parameters $u_{1,i}$ and $u_{2,i}$ from the source contour to the desired points n along the target contour circumference s'_n (Fig. 5). Following interpolation, the source deformations were mapped to the target geometry for all t according to Eqs. (7) and (8)

$$q_{1,n,t=t_1} = q_{1,n,t=0} \cdot u_{1,n,t=t_1} \tag{7}$$

$$q_{2,n,t=t_1} = q_{2,n,t=0} \cdot u_{2,n,t=t_1} \tag{8}$$

Final deformations of the target geometry were obtained by plotting (q_1,q_2) datasets for all t on stationary **X** and **Y** axes.

2.2. Evaluation

Two source contour datasets were selected from 11 PMHS experiments (Kuppa et al., 2003; Yoganandan et al., 2008) to evaluate algorithm suitability. These experiments employed PMHS positioned in a normal vehicle seated posture and subjected to a lateral sled impact at ΔV=6.7 m/s in one of two boundary conditions: flat rigid wall or 20–30° anterior-oblique wall. A target geometry was developed from the external contour of the torso at the T11 vertebral level of the Visible Male from the US-NIH Visible Human Project (Spitzer et al., 1996). This target contour was discretized into 192 nodes for future use with a FE model.