VERTEBRAL KINEMATIC DESCRIPTIONS BASED ON IN VIVO MEASUREMENT OF SURFACE MARKER MOTIONS

Xudong Zhang, Jinjun Xiong, and Angela Bishop
Biomechanics and Ergonomics Laboratory, University of Illinois, Urbana, IL, USA
E-mail: xudong@uiuc.edu  Web: www.staff.uiuc.edu/~xudong

INTRODUCTION

Among various techniques and systems for acquiring spinal kinematic data (Gracovertsky et al., 1995; Lundberg, 1996; Marras et al., 1992), the most direct non-invasive in vivo measurement still relies on the use of skin-surface markers or sensors. Markers as skin-based rigid posts have been devised to estimate lumbarsacral orientation (Anderson et al., 1986; Chen et al., 1997) and external spinal profile (Bryant et al., 1989). Spherical markers may also be directly adhered to the skin over spinous processes to attain gross spinal kinematic information (Gram & Hasan, 1999). However, a more elaborate assessment of the kinematics of individual vertebrae, through measuring the surface marker motions, has been difficult. This is due mainly to, besides other challenges (Lundberg, 1996), the fact that the small separation between spinous processes poses a limit on the size of or the distance between markers (or sensors). This limit would be even more stringent for dynamic situations when marker interference becomes more probable. Recent advances in instrumentation technology have enabled considerable improvement on the accuracy and resolution of the motion measurement systems. For instance, an evaluation of contemporary motion measurement systems (Richards, 1999) showed that a millimeter level of resolution (minimal discriminable inter-marker distance) is achievable by some of the newest opto-electronic systems. Such technological advancement can be fully exploited to better capture and understand the kinematic characteristics of the human spine.

The purpose of this study was to explore the feasibility of quantifying vertebral kinematics by in vivo measurement of skin-surface marker movements. We proposed a novel method to derive, from measured surface marker trajectories, the centers of rotation for individual vertebrae during two-handed symmetric lifting.

METHODS

Ten adult subjects (5 m, 5 f) participated in an experiment in which they lifted a 15-lb box from the floor up to a chest-height shelf, at a self-preferred pace and in a sagittally symmetric manner. Reflective spherical markers were placed over subjects’ surface landmarks corresponding to major body joints (e.g., shoulders, elbows, hips, and knees) and seven spinal processes (C7, T7, L1-L5). Only the ones illustrated in Fig. 1a were relevant and thus analyzed in the current study. Note the markers in the lumbar spine region were 9 mm in diameter, and the rest were 25 mm. The marker placement was conducted under the guidance of an experienced physical therapist. A five-camera Vicon 250 system

![Figure 1](image-url)
was employed to capture the motions at a frequency of 120 Hz. The acquired 3D marker location data were projected onto the mid-sagittal plane and thus simplified as 2D data, while the bisection of two greater trochanter markers was used to represent the hip joint (Fig. 1a). The derivation of vertebra center of rotation (COR) locations was based on the assumption that a vertebral segment follows a circular trajectory with respect to a local reference frame affixed to its adjacent segment(s). Given that there was only one marker attached to each presumably rigid vertebral segment, construction of a local frame was made possible by utilizing the COR coordinates pre-determined for the lower adjacent segment (Fig. 1b). This procedure was repeated recursively in the “bottom-up” direction, with the initial frame constructed from known coordinates of the L5 and hip markers. An optimization routine was created to identify the circle that best fit a marker trajectory expressed in the respective local coordinate system, by minimizing the fitting error:

\[ e(a,b,r) = \frac{1}{n} \sum_{i=1}^{n} \sqrt{(x_i - a)^2 + (y_i - b)^2 - r^2} \]

where \( x_i \) and \( y_i \) (\( i = 1 \ldots n \)) are the marker coordinates in the local frame, \( (a, b) \) is the center of the circle, and \( r \) the radius. Algorithm determining the \( a, b, \) and \( r \) of the maximum-likelihood circle (Rorres & Romano, 1997) was implemented numerically based on the Nelder-Mead simplex search (1965).

RESULTS AND DISCUSSION

Table 1 presents a sample of the results from this study. The initial inter-marker distance \( (d) \) values provide a reality-check of the marker placement and a reference for the derived centers of rotation. Except for the upper thoracic (C7-T7) segment, the COR locations (not presented) and \( r \) values seem plausible; the latter varied in a reasonable range across subjects, and had very small within-subject trial-to-trial variabilities. The assumed circularity of marker trajectories, and adequacy of the proposed analysis method, are supported by favorable \( e/r \) ratios for all but the C7-T7 segment.

<table>
<thead>
<tr>
<th>C7</th>
<th>T7</th>
<th>L1</th>
<th>L2</th>
<th>L3</th>
<th>L4</th>
<th>L5</th>
</tr>
</thead>
<tbody>
<tr>
<td>( d )</td>
<td>192±8</td>
<td>174±11</td>
<td>27±2</td>
<td>23±2</td>
<td>22±2</td>
<td>22±2</td>
</tr>
<tr>
<td>( r )</td>
<td>636±307.9</td>
<td>329±165</td>
<td>68.5±38.4</td>
<td>58.9±31.9</td>
<td>46.3±21.6</td>
<td>22.8±7.0</td>
</tr>
<tr>
<td>( e/r )</td>
<td>.15±.098</td>
<td>.05±.037</td>
<td>.01±.007</td>
<td>.02±.007</td>
<td>.04±.035</td>
<td>.07±.034</td>
</tr>
</tbody>
</table>

SUMMARY

This work has demonstrated the viability of using in vivo measurement of spinal surface marker motions and novel analytical means to quantify vertebral kinematics. Such capability will facilitate investigating the biomechanics of human spine, particularly the lumbar spine, in a more discerning yet non-invasive manner.

REFERENCES