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Short communication

Between-session reliability of opto-electronic motion capture in measuring sagittal posture and 3-D ranges of motion of the thoracolumbar spine

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ABSTRACT

This study evaluated between-session reliability of opto-electronic motion capture to measure trunk posture and three-dimensional ranges of motion (ROM). Nineteen healthy participants aged 24–74 years underwent spine curvature, pelvic tilt and trunk ROM measurements on two separate occasions. Rigid four-marker clusters were attached to the skin overlying seven spinous processes, plus single markers on pelvis landmarks. Rigid body rotations of spine marker clusters were calculated to determine neutral posture and ROM in flexion, extension, total lateral bending (left-right) and total axial rotation (left-right). Segmental spine ROM values were in line with previous reports using opto-electronic motion capture. Intraclass correlation coefficients (ICC) and standard error of measurement (SEM) were calculated as measures of between-session reliability and measurement error, respectively. Retroreflective markers showed fair to excellent between-session reliability to measure thoracic kyphosis, lumbar lordosis, and pelvic tilt (ICC = 0.82, 0.63, and 0.54, respectively). Thoracic and lumbar segments showed highest reliabilities in total axial rotation (ICC = 0.78) and flexion-extension (ICC = 0.77–0.79) ROM, respectively. Pelvic segment showed highest ICC values in flexion (ICC = 0.78) and total axial rotation (ICC = 0.81) trials. Furthermore, it was estimated that four or fewer repeated trials would provide good reliability for key ROM outcomes, including lumbar flexion, thoracic and lumbar lateral bending, and thoracic axial rotation. This demonstration of reliability is a necessary precursor to quantifying spine kinematics in clinical studies, including assessing changes due to clinical treatment or disease progression.

1. Introduction

Spinal disorders remain common and costly complaints in clinical practice (Martin et al., 2008). Various disorders, including back pain, developmental disorders, vertebral fracture, and spinal stenosis, impact trunk posture and kinematics (Christe et al., 2017; Chun et al., 2017; Kuwahara et al., 2016; Schmid et al., 2016). Therefore, objective evaluation of trunk posture and motion can help in assessing the functional impact of spinal disorders (e.g. diagnosis of segmental instability, assessment of spine mobility), and in the development and evaluation of evidence-based treatments for spinal disorders (e.g. surgical planning, tracking rehabilitation progress).

Opto-electronic motion capture systems have been used to measure trunk posture and motion (Hidalgo et al., 2012; Ignasiak et al., 2017; Marich et al., 2017; Nairn et al., 2013; Preuss and Popovic, 2010; Rast et al., 2016; Schmid et al., 2016), but there is no preferred or standardized method. Establishing motion capture reliability in assessing three-dimensional spine position would facilitate its use in clinical studies and clinical trials. A few studies have reported between-session reliability of motion capture in measuring trunk posture (Dunk et al., 2004, 2005; Muyor et al., 2017) and range of motion (ROM) (Hidalgo et al., 2012; Montgomery et al., 2011; Rast et al., 2016). However, none of these utilize marker clusters applied to the spine, which are needed for appropriate assessment of three-dimensional motion including evaluation of non-sagittal and coupled motions of the spine. Furthermore, only one study has examined within-session reliability of motion with marker clusters on the spine (Schinkel-Ivy et al., 2015). Therefore, the aim of this study was to measure thoracic

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kyphosis (TK), lumbar lordosis (LL), and pelvic tilt (PT), as well as three-dimensional spine flexion, extension, lateral bending, and axial rotation ROMs, with three-dimensional marker clusters on the spine, and to determine the between-session reliability of these measurements.

2. Methods

2.1. Participants

Nineteen healthy (8 female) volunteers participated in this study. The mean ± SD (range) age, height, weight, and BMI of the participants were 47 ± 17 (24–74) years, 172 ± 7 (162–185) cm, 71.4 ± 13.9 (44.7–98.1) kg, and 24.0 ± 3.3 (17.0–31.0) kg/m^2, respectively. Individuals with recent back pain, history of spinal surgery, traumatic fracture, thoracic deformity, or conditions that affect balance, movement, or ability to stand were excluded. This study was approved by the Institutional Review Board of Beth Israel Deaconess Medical Center, and all participants provided written informed consent before participation.

2.2. Procedure

Each participant underwent the same set of measurements on two separate occasions, an average of 7 days apart (range 2–14 days). In each session, before marker placement, spine curvature and pelvic tilt were measured with the flexicurve and Palpation Meter, respectively (see Supplement 1 for details and related results). Then anatomical landmarks were found for marker placement, but no marks were made on the skin (e.g. with grease pencil or marker) as they might have affected placement in the second session. Rigid clusters with four markers each were attached to the skin overlying the T1, T4, T5, T8, T9, T12 and L1 spinous processes using double-adhesive tape. Pelvic markers were placed on the posterior (PSIS) and anterior (ASIS) superior iliac spines and iliac crests. An additional 69 single markers were placed on C7, head, sternum and clavicles, and extremities. Marker data was collected with a 10-camera motion analysis system (Vicon Motion Systems, Oxford, UK) while the participant stood in the middle of the room with feet shoulder-width apart. Marker positions were first captured in the neutral upright standing posture (5 s). Next, participants were instructed to move their trunk toward full flexion, extension, right and left lateral bending, and right and left axial rotation as smoothly as possible, and hold each position for 5 s while data was collected (Fig. 1). The same protocol was followed and all participants received consistent instructions in both sessions.

2.3. Data reduction, processing, and analysis

Marker positions were averaged over one second from each trial with minimal movement and/or noise in the marker data (or the first one second if no movement or noise was seen). A custom MATLAB (The Mathworks, Inc., Natick, MA, USA) program was used to evaluate 3D orientations. A local coordinate system was created for each spinal marker cluster and the pelvis with x positive to the right. In the spine y and z were normal and tangent to the neutral spine curvature, respectively. In the pelvis y and z were parallel and perpendicular to the plane of the ASIS and PSIS markers, respectively. An Euler angle sequence of x (flexion-extension), y (lateral bending), z (axial rotation) was used to calculate segment orientation and relative orientations between segments, following previous studies (Cotter et al., 2014; Preuss and Popovic, 2010). The relative rotations between clusters in the neutral position were measured for thoracic kyphosis (T1-L1) and lumbar lordosis (L1 – Sacrum), and the orientation of the pelvis for pelvic tilt. Similarly, the relative rotations in ROM trials were calculated to determine ROM outcomes. ROM was defined as the difference in angle for a spine segment (or the pelvis) between neutral posture and the trial. Total ROM was defined as the largest magnitude of angular motion between neutral, flexion, and extension trials (for flexion – extension), and between neutral, left, and right trials (for lateral bending and axial rotation). Circle fitting (Schmid et al., 2016) and polynomial fitting (Ignasiak et al., 2017) approaches were also applied to estimate sagittal plane angles from marker data, with details and results provided in Supplement 2.

2.4. Statistical analysis

Primary outcomes were magnitude and reliability of thoracic (T1-L1), lumbar (L1 – Sacrum), and pelvic neutral posture and ROMs. Specifically, the primary outcomes for flexion and extension trials were flexion-extension angles. Since lateral bending and axial rotation include significant coupling with other motions, total ROMs of both primary and coupled motions were examined. Secondary outcomes, including ROMs for left and right ROMs separately and for thoracic sub-segments, are presented in Supplement 3. Outcomes were checked for normality by Shapiro-Wilk tests.

Reliability of each outcome was examined using intraclass correlation coefficients (ICC), and classified as poor (ICC < 0.4), fair to good (ICC between 0.4 and 0.75) or excellent (ICC > 0.75) (Shrout and Fleiss, 1979). Standard error of measurement (SEM) as a parameter of absolute reliability indicates magnitude of error and within-subject variability across repeated trials and was calculated as:

$$SEM = SD\sqrt{1 - ICC} \quad (1)$$

Reliability can be improved by averaging repeated trials, which provides a better estimate of the true measure. Given the ICC for an individual trial, *ICC*(*1*), the ICC for *m* repeated trials can be estimated using the Spearman-Brown formula:

$$ICC(m) = \frac{mICC(1)}{1 + (m-1)ICC(1)} \quad (2)$$

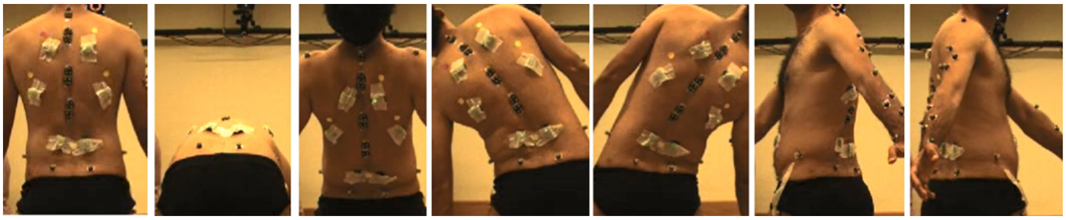

Fig. 1. Posterior views of a subject performing range of motion trials, with spine marker clusters visible. From left to right: neutral posture, full flexion, extension, left lateral bending, right lateral bending, left axial rotation, right axial rotation trials.