

# Errors Associated with Using Skin-Mounted Markers to Estimate Vertebral Position and Movement in Participants with Chronic Low Back Pain

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**INTRODUCTION:** Chronic low back pain (cLBP) is a debilitating, costly, and resource-demanding condition.[1] Patient diagnosis and treatment may be improved by objectively measuring lumbar spine motion to identify aberrant motion that may overload the spine and induce pain. Typically, non-invasive biomechanical assessments are performed with optoelectronic motion capture (MoCap) using retroreflective markers or inertial measurement units (IMUs) attached to the skin to objectively measure *in vivo* range of motion (ROM). This approach inherently contains errors due to marker misplacement on palpated bony landmarks and motion of the skin relative to the underlying bone (*i.e.*, soft tissue artifact (STA)).[3] Estimates of lumbar spine STA have been limited to young, healthy participants in static positions [4], so errors in measuring dynamic lumbar spine kinematics using skin-mounted sensors remain unknown. This study aimed to quantify palpation errors and lumbar STA from MoCap at lumbar vertebrae L1 and L5 during dynamic motions performed by participants with cLBP. We hypothesized that: 1) static placement errors are greater at L5 than L1; 2) STA is greater during flexion/extension than during lateral bending; 3) dynamic STA is greater at L5 than at L1; and 4) STA when measuring L1 relative to L5 motion can be predicted by age and BMI.

**METHODS:** Participants in this IRB-approved study were at least 18 years old and had cLBP, defined as LBP >3 months with pain existing >50% of the time in the last six months. Exclusion criteria were BMI >35 kg/m<sup>2</sup>, pregnancy, or inability to perform lumbar motion tests. An experienced orthopaedic physical therapist followed a standardized process to place reflective marker clusters on the skin over the L1 and L5 spinous processes (Figure 1). Participants stood within a dynamic biplane radiography (DBR) system and performed three trials each of dynamic flexion/extension and lateral bending while DBR (20 images/s; X-ray: kV=85, mA=320, pulse width=4 ms) and conventional MoCap (12-camera Vicon Vantage, 120 frames/s) were simultaneously recorded. Vertebral bone motions were measured using a validated, volumetric model-based tracking process that matched digitally reconstructed radiographs from subject-specific CT-based bone models to the biplane radiographs with an accuracy of 0.3mm or better in translation and 0.5° or better in rotation.[5] Marker clusters were tracked using traditional software (Vicon). A custom calibration object was imaged simultaneously by DBR and MoCap to place marker clusters and vertebral bone motion in the same coordinate system. Differences between DBR and MoCap data (the base of the cluster, touching the skin) were calculated for each repetition, then averaged over the three repetitions for each motion to obtain a single dataset for each participant which was included in the analysis. Marker cluster placement errors and STA during dynamic motion were quantified by the root mean square error (RMSE), using DBR as the reference standard. Marker cluster placement errors in the static upright position were removed prior to calculating STA during dynamic motion. Paired T-tests compared L1 to L5 errors and flexion/extension to bending errors. Multiple regression was used to predict average STA using age and BMI as independent variables, with significance set at  $p < 0.05$  for all tests. Statistical analysis was performed in Minitab v21.4.

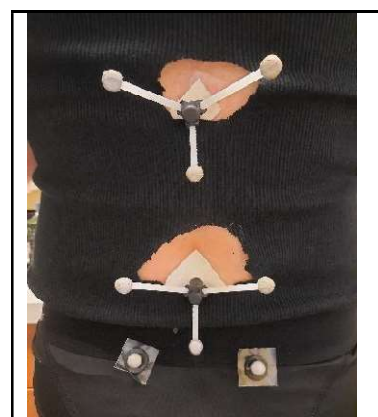
**RESULTS:** Data processing has been completed for 20 out of 50 cLBP participants who completed the protocol (11F, 9M; 51.1±16.3 yrs; BMI 25.5±3.5kg/m<sup>2</sup>). L1 marker clusters were placed more superior to the L1 spinous process ( $p<0.001$ ) and vertebral body ( $p<0.001$ ) than L5 clusters, but the L5 clusters were placed more posterior to the spinous process ( $p<0.001$ ) and vertebral body than L1 clusters (Table 1). A total of 120 dynamic movement trials were included in the analysis. L1 relative to L5 STA during flexion/extension ( $9.1^{\circ}\pm6.3^{\circ}$ ; peak error:  $24.3^{\circ}$ ) was larger ( $p=0.007$ ) than during lateral bending ( $4.6^{\circ}\pm2.5^{\circ}$ ; peak error:  $9.8^{\circ}$ ). Cluster estimates of bone rotations were greater at L5 for both motions (Flexion/extension =  $12.0^{\circ}\pm7.9^{\circ}$ , peak error:  $33.4^{\circ}$ ; Lateral bend =  $7.1^{\circ}\pm7.5^{\circ}$ , peak error:  $25.0^{\circ}$ ) than at L1 (Flexion/extension =  $7.1^{\circ}\pm7.2^{\circ}$ , peak error:  $29.7^{\circ}$ ; Lateral bend =  $2.8^{\circ}\pm2.4^{\circ}$ , peak error:  $9.0^{\circ}$ ), ( $p=0.002$  and  $p=0.014$ , respectively). No statistically significant linear dependence of age or BMI on mean STA was found during flexion/extension or lateral bending. Errors in measuring bone motion typically peaked at the end ROM and varied across participants (Figure 2).

**DISCUSSION:** This interim analysis suggests that palpation errors and dynamic STA errors while performing flexion/extension and lateral bending are large and variable across individuals with cLBP. Correcting for STA in the lumbar spine may be challenging, as the errors are different depending on the vertebra being tracked and the motion being performed, and the STA for an individual does not appear to be related to their age or BMI.

**CLINICAL RELEVANCE:** Clinicians should avoid using data from skin-mounted markers or IMUs to infer motion of individual lumbar vertebrae during flexion/extension and lateral bending in patients with cLBP. Furthermore, estimates of spine loading based upon any tracking device placed on the skin or based upon “typical” intervertebral motion are likely inaccurate due to STA and the unique orientation and motion of each vertebra in patients with cLBP.

**REFERENCES:** 1. Deyo R, et al. *J Pain*. 2014; 2. Knox P, et al. *Arch Phys Med Rehabil*. 2021; 3. Leardini A, et al. *Gait Posture*. 2005; 4. Xi X, et al. *Front. Bioeng Biotechnol* 2022; 5. Dombrowski M, et al. *Eur Spine J*. 2018.

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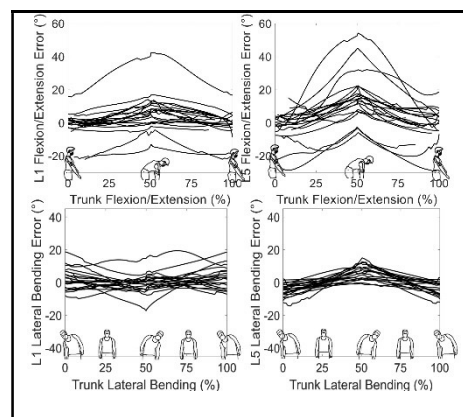


**Figure 1.** Marker clusters attached to skin at L1 and L5 relative to posterior superior iliac spine markers.

Table 1. Static positions of MoCap Marker Clusters

		Distance from spinous process Mean Error (SD) (mm)	Distance from vertebral body Mean Error (SD) (mm)
L1	A(+) P(-):	-12.2 (5.8)	-78.2 (7.6)
	S(+) I(-):	39.6 (16.4)	27.0 (17.7)
L5	A(+) P(-):	-35.9 (10.6)	-94.1 (9.1)
	S(+) I(-):	15.2 (14.5)	4.6 (14.6)

SD=standard deviation; mm=millimeters; A=anterior; P=posterior; S=superior; I=inferior



**Figure 2.** STA over the motion cycle for all participants. Each line represents STA for one participant.