Between-session Reliability of Subject-Specific Musculoskeletal Models of the Spine Derived from Optoelectronic Motion Capture Data

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Introduction

Optoelectronic motion capture data are often used for scaling of musculoskeletal models to an individual's anthropometry. However, there is known error in optoelectronic motion capture due inherent system performance[1] and more notably due to variation in marker placement on anatomical landmarks[2-4]. While these concerns have been well studied in gait models, there has been limited prior investigation into how this variation might affect marker-estimated spine models and spinal loading predictions.

Therefore, the aim of this study was to investigate how variation in the placement of anatomical markers affects the reliability of body segment scaling, estimated spine curvature, and resulting compressive spine loading outcomes when creating subject-specific musculoskeletal models.

Methods

Nineteen healthy participants aged 24-74 years underwent the same set of measurements on two separate occasions. Retroreflective markers were placed on anatomical regions, including C7, T1, T4, T5, T8, T9, T12 and L1 spinous processes, pelvis, upper and lower limbs, and head. We created full-body musculoskeletal models with detailed thoracolumbar spines, and scaled these to create subject-specific models for each individual and each session. Models were scaled from distances between markers, and spine curvature was adjusted according to marker-estimated measurements. Using these models, we estimated vertebral compressive loading from T1 to L5 for five different standardized postures: neutral standing, 45˚ trunk flexion, 15˚ trunk extension, 20˚ lateral bend to the right, and 45˚ axial rotation to the right. Intraclass correlation coefficients (ICCs) and standard error of measurement were calculated as measures of between-session reliability and measurement error, respectively.

Results and Discussion

Of the nineteen healthy subjects, two subjects were excluded from analysis due to non-visible retroreflective markers on the pelvic ASIS or on the L1 vertebra. For body segment scaling, segment lengths were not different between sessions ($p>0.05$). The measurements with excellent reliability (ICC > 0.75) were the head and neck length and width, humeri and radii, spine and foot length and width. All other scaling measurements had fair reliability with ICCs ranging from 0.46 – 0.75. Spine curvature was not different between sessions, however the variability was larger for lordosis than kyphosis. Both measures had excellent reliability with ICCs>0.75. Bland Altman plots of between session measures showed no systematic differences or proportional biases.

Subject-specific spine loading between sessions was not significantly different for all activities. Interquartile ranges and total range of mean difference were similar across all levels of the spine for all simulated activities. Mean difference in compressive spine loading during flexion between sessions is shown in Figure 1. The ICC values of spine loading from T1 to L5 were mostly excellent, with 91% of ICC point estimates being greater than 0.75 for all activities.

This is the first study to determine the reliability of spine loading determined from marker-based subject-specific musculoskeletal models. We found that larger differences in spine loading between sessions (>15%), at any level, were corresponding to larger differences (>10%) in lordosis or kyphosis between sessions. This indicates much of our spine loading differences can be ascribed, at least in part, to differences in spine curvature, and that precise and accurate assessment and implementation of spine curvature is crucial for creating subject-specific musculoskeletal models of the spine.

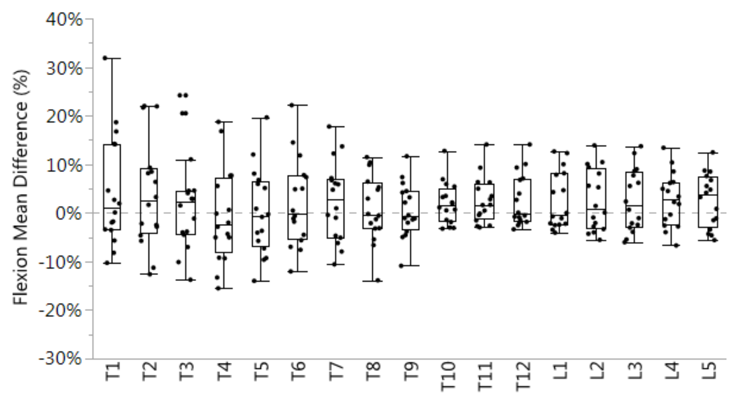

Figure 1: Mean difference in compressive spine loading for flexion between sessions. Box plots show median and inter-quartile range, and black dots represent individual data points.

Significance

Overall, this information is a necessary precursor of using motion capture data to estimate spine loading with subject-specific musculoskeletal models, and suggests that marker data will deliver reproducible subject-specific models and estimates of spine loading. This informs the conduct and interpretation of future studies on dynamic spine loading, which are important for gaining insight into mechanisms contributing to back pain, vertebral fractures and other musculoskeletal injuries.

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