In-Vivo Kinematics of the Tibiotalar and Subtalar Joints in Asymptomatic Subjects with Application to Chronic Ankle Instability

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Introduction/Purpose: Measurements of joint angles and translations (i.e. kinematics) are essential to understand the pathomechanics of ankle disease and functional changes following treatment. Traditional motion capture techniques, which track the positions of reflective markers adhered to the skin, cannot measure motion of the tibiotalar and subtalar joints independent of one another. To overcome this limitation, we used high-speed dual fluoroscopy (DF), an x-ray videography technique, to quantify in-vivo kinematics of healthy asymptomatic ankles during activities of daily living. Using these kinematics as baseline data, our secondary objective was to assess preliminary kinematic differences between chronic ankle instability (CAI) patients and asymptomatic control subjects.

Methods: High-speed DF images of the hindfoot of ten healthy, asymptomatic adults and four adults with CAI were acquired during treadmill walking at 0.5 m/s and 1.0 m/s and during a single-leg, balanced heel-rise. Three-dimensional (3D) CT models of the calcaneus, tibia, and talus and DF images served as input to the validated model-based markerless tracking software that quantified in vivo kinematics for the tibiotalar and subtalar joints. Dynamic joint kinematics and mean range of motion (ROM) were calculated and reported as dorsi/plantarflexion (D/P), inversion/eversion (In/Ev) and internal/external rotation (IR/ER) angles or translations along the medial/lateral (ML), anterior/posterior (AP), and superior/inferior (SI) directions.

Results: During gait, the tibiotalar joint had significantly greater D/P ROM than the subtalar joint (0.5 m/s: $p=0.004$; 1.0 m/s: $p=0.003$). The subtalar joint had significantly greater In/Ev (0.5 m/s: $p < 0.001$; 1.0 m/s: $p < 0.001$) and IR/ER (0.5 m/s: $p=0.01$; 1.0 m/s: $p=0.02$) ROM than the tibiotalar joint. However, during balanced heel-rise, D/P and In/Ev were significantly different between the two joints ($p < 0.001$; $p < 0.001$). For AP translation, subtalar ROM was significantly greater than tibiotalar ROM during walking at 0.5m/s ($p=0.002$). CAI patients often demonstrated rotational profiles with dynamic trends that fell outside the 95% confidence intervals of the asymptomatic subjects (Figure 1). CAI patients exhibited smaller ROM than asymptomatic subjects. However, only 0.5 m/s tibiotalar SI translational ($p=0.049$) and 1.0 m/s subtalar In/Ev ($p=0.03$) ROM were significant.

Conclusion: To our knowledge, this is the first study to quantify in-vivo joint angles and translations in asymptomatic and CAI subjects. Our results support the belief that the tibiotalar joint is primarily responsible for D/P, while the subtalar joint facilitates In/Ev and IR/ER. Secondary rotational contributions suggest that both joints undergo complex, 3D motion. Our comparison of CAI and asymptomatic subjects is not conclusive, yet suggests that a larger sample size will detect significant differences. With a larger sample size, dual-fluoroscopy may provide insight into the clinical relevance of altered kinematics and the pathomechanics responsible for ankle instability and other pathologies.

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