Modeling of lower limb joint loading in patients after hip replacement during gait: Validation of a MATLAB tool for personalizing of OpenSim models

DIE UNTERNEHMERISCHE HOCHSCHULE

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OBJECTIVE

Musculoskeletal (MSK) simulations are widely used to estimate joint loading after total hip replacement (THR), but standard models often neglect patient-specific anatomy, limiting biomechanical accuracy [1,2]. This study investigates whether personalizing femoral geometry, specifically neck-shaft angle (CCD), anteversion angle (AVA), and varus-valgus (VV) alignment (Figure 1), impacts joint force predictions during gait. Building on prior single-subject findings by Kainz et al. [3], the aim was to investigate whether isolated anatomical adjustments are sufficient to produce relevant biomechanical changes, or if full personalization is required to capture joint loading effects.

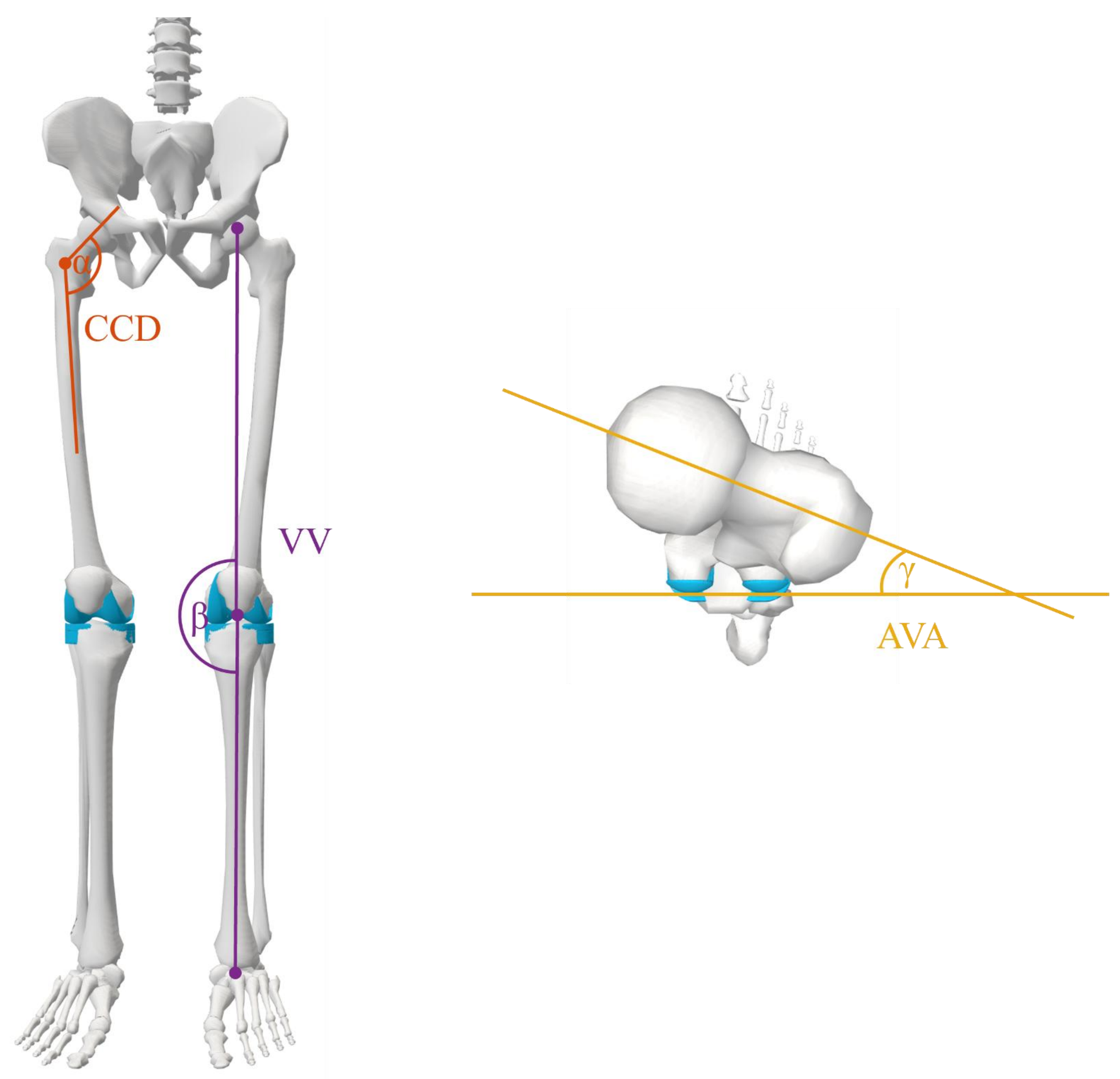

Fig. 1: Key anatomical parameters relevant to lower limb biomechanics. Coronal view (left), axial view (right)

METHODS

To address this, the MATLAB-based tool Torsion Tool [4] was employed to modify OpenSim models using patient-specific CCD, AVA, and VV values derived from 3D biplanar radiography (EOS imaging). Five model variants were generated for each of the 32 patients approximately one-year post-THR: a generic scaled model (RAW), three models with isolated adaptations (CCD, AV, and VV), and a combined model (ALL). These models underwent a standardized simulation pipeline comprising inverse kinematics, inverse dynamics, static optimization, and joint reaction force analysis. Statistical non-parametric mapping (SnPM) was used to evaluate the differences in vertical joint contact forces at the hip, lateral knee, and medial knee joints during the stance phase of the gait cycle.

RESULTS

The SnPM analysis confirmed that femoral geometry personalization significantly affects hip (see Figure 2) and knee joints loading during gait, with a clear model-dependent difference in vertical joint contact forces across the stance phase.

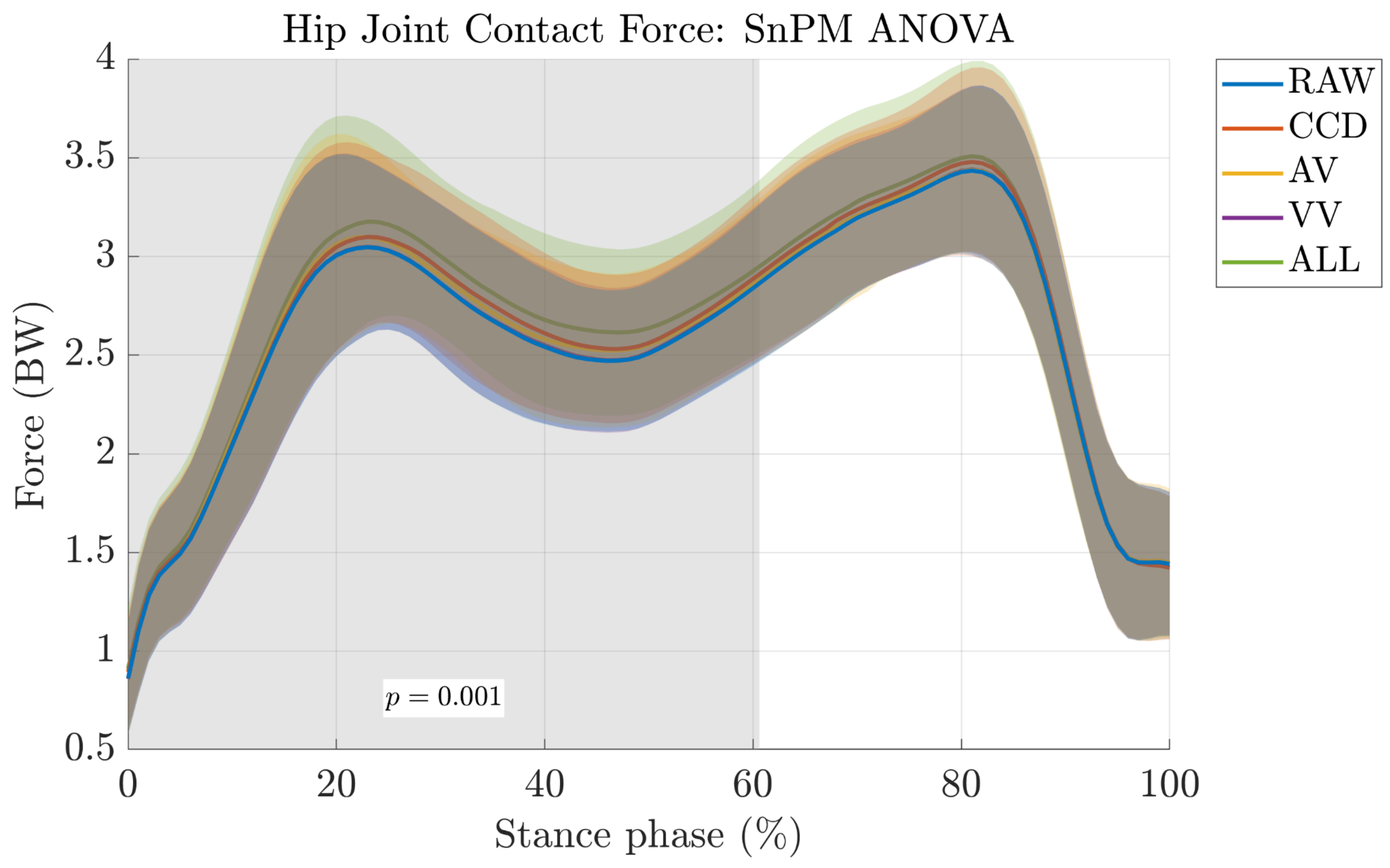

Fig. 2: Mean vertical hip joint contact force curves across all model conditions ± 1 SD.

Joint loading responses varied systematically with the degree and direction of CCD change: hip joint contact forces increased with CCD elevation and decreased with CCD reduction, while the opposite trend was observed at the knee joint. Figure 3 shows these effects for participants with increased CCD, showing elevated hip contact forces and slightly reduced lateral knee joint loading. Moderate changes in AVA or VV had minimal effects.

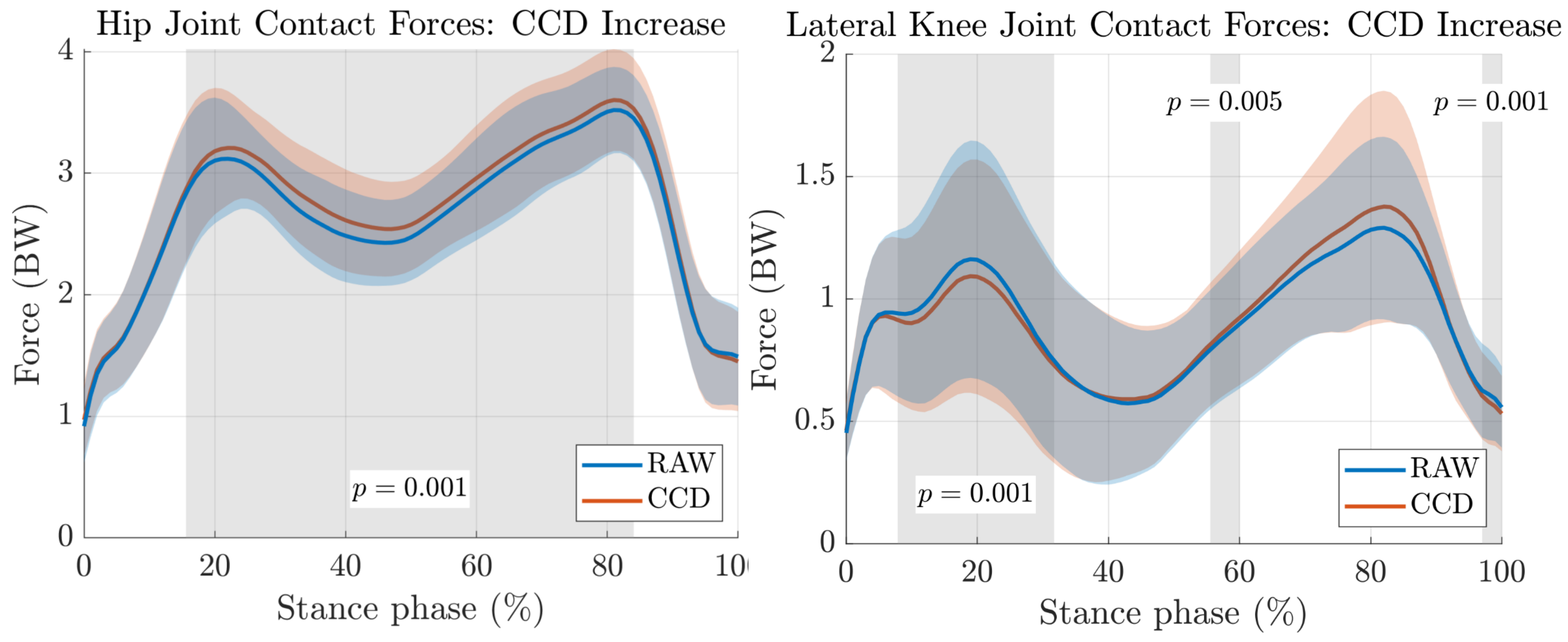

Fig. 3: Vertical hip (left) and lateral knee (right) joint contact force patterns for participants with increased CCD compared to the RAW model.

CONCLUSION

Anatomical personalization, especially of the femoral CCD angle, significantly influence joint loading predictions in MSK simulations post-THR. Changes in CCD angle had clear, direction-dependent effects, while AVA and VV showed minimal impact. Prioritizing key parameters can enhance biomechanical accuracy and support personalized surgical and rehabilitation strategies.

References: [1] Akhundov, R. et al. (2022). *Is subject-specific musculoskeletal modelling worth the extra effort or is generic modelling worth the shortcut?* PLOS ONE, 17(1), e0262936. https://doi.org/10.1371/journal.pone.0262936
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