A Detailed 3D Analysis of Hip Center of Rotation Trajectory and its Effects on Impingement-Free Range of Motion: A 3D Dynamic Analysis of 1,222 Hips

Mohammadreza Movahhedi, James Pruneski, Eduardo N. Novais, Young-Jo Kim, Ata M. Kiapour
Department of Orthopaedic Surgery, Boston Children's Hospital, Harvard Medical School
Mohammadreza.Movahhedi@childredns.harvard.edu

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INTRODUCTION: Hip joint is often thought about as a ball and socket joint with a fixed center of rotation and no translation. This traditional view has been the basis for several simulation platforms to study hip impingement and instability, and to optimize treatment planning and associated outcomes. There has been a growing number of in vivo imaging and cadaveric studies, suggesting potential hip translations. A recent MRI study has shown an average translation of 2 mm, with up to 7 mm translations in certain positions, among subjects with asymptomatic hips. Such, substantial magnitudes of translation can completely change hip contact and impingement patterns with downstream effects on the treatment plans. However, we know little about how hip translation may influence hip impingement. Here we used a validated simulation platform, capable of simulating hip translation during impingement analysis, to map the trajectory of the hip center of rotation (COR) and its effects on impingement-free hip range of motion.

METHODS: Following IRB approval, New Mexico Decedent Image Database (NMDID) was queried to identify CT scans with full coverage of the hip and femur from subjects with no documented bone and joint pathology (n=1,222 hips, 611 subjects, age: 30.4 ± 8.8; 67% males). A custom-developed and validated program (VirtualHip, Boston Children's Hospital) was used to automatically segment the bones, identify landmarks, and the define anatomical coordinate system based on ISB recommendations. The pelvis was then fixed in 3D and the femur was moved to simulate uniplanar rotations (i.e., flexion: 0-150, extension: 0-50, abduction/adduction: 0-75, internal /external rotations: 0-75). The simulations were first done assuming a fixed hip COR (no translation) and then repeated by incrementally allowing the hip COR to translate by up to 5 mm with increments of 1 mm, avoiding bone-to-bone penetration or hip dislocation (distance between the femoral head and acetabulum exceeding the joint space width measured at neutral). Mixed linear models were used to evaluate the relationships between COR translation and impingement-free rotation (maximum rotation prior to impingement). We also, measured how many hips (out of 1,222) were able to achieve each range of motion (the effect of translation on the range of motion). Finally, we mapped the path of hip COR during the tested range of motion.

RESULTS: The effect of COR translation on achieved impingement-free range of motion along with COR trajectories are shown in Figure 1. Hip flexion was associated with COR posterior (by 4.0±0.9 mm), lateral (only after 100°, by 3.6 ±1.4 mm), and superior (only after 100°, by 2.0 ±1.8 mm) translations (P<0.001). Hip extension was only associated with anterior COR translation (by 0.8 ± 0.7 mm, P<0.001). Hip adduction was associated with anterior (by 2.9 ± 1.3 mm), lateral (by 4.0 ± 1.3 mm), and superior (by 4.4 ± 0.6 mm) translations (P<0.01). Hip abduction was only associated with medial (by 2.6 ± 1.5 mm) and inferior (by 2.9 ± 1.7 mm) translations (P<0.02). There were minimal COR translations during hip internal rotations (P>0.05). Hip external rotation was associated with anterior (by 3.7 ± 1.4 mm) and inferior (by 1.2 ± 1.3 mm) translations (P<0.05).

DISCUSSION: This is the first study to map the hip COR trajectory under common movements in a large cohort of patients. The current findings highlight the importance of hip translation (non-fixed COR) on the physiologic hip range of motion. Considering the fact that the hip is not a perfect ball and socket joint with an aspherical femoral head, translation is required to accommodate physiologic rotation (e.g., glide mechanism) without bony impingement between the femur and pelvis. These preliminary observations also highlight the need for a comprehensive assessment of normal and pathologic hip translation along with their role in biomechanics, injury risk, and response to treatment.

CLINICAL RELEVANCE: A clear understanding of the role of hip translation in hip function and health will improve clinical care through better diagnosis and personalized treatment planning, which can ultimately lead to improved treatment outcomes, in particular lower risk of osteoarthritis.

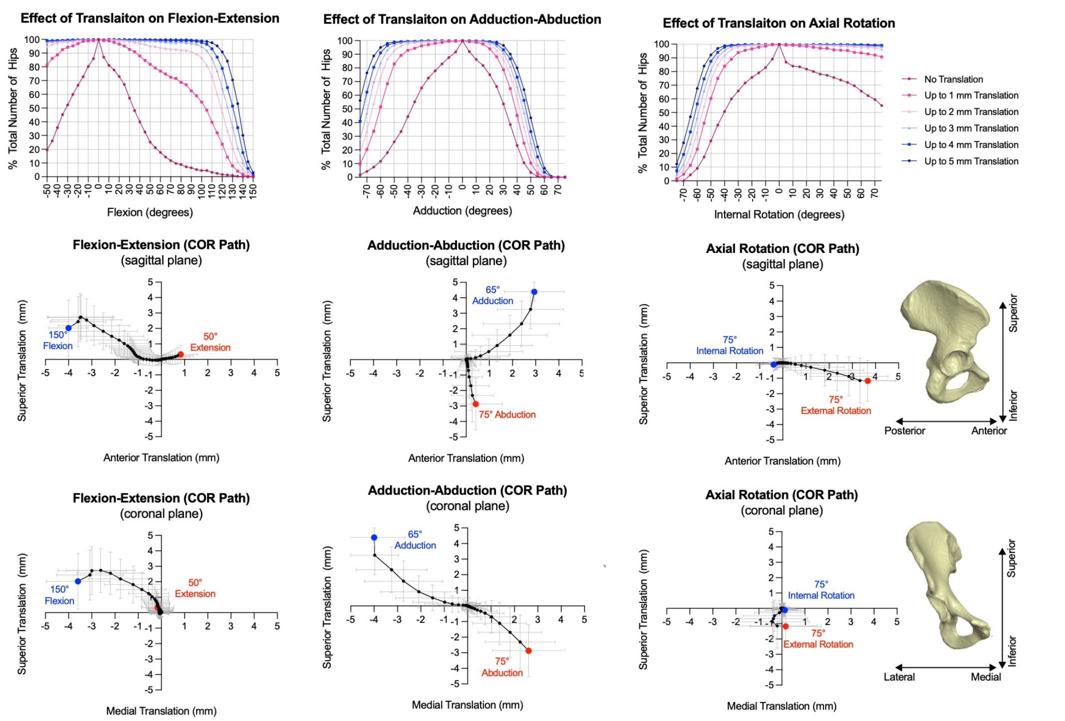

Figure 1. Effect of hip translation on impingement-free maximum hip rotation and COR trajectory under simulated motions.