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Estimating Infant Hip Joint Moments Using a Novel Musculoskeletal Model

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INTRODUCTION: Musculoskeletal models offer a convenient method to non-invasively study human development, function, and pathologies. While adult musculoskeletal models have been extensively studied [1], infant populations have been widely underserved. However, understanding infant joint biomechanics during the first year of life is vital considering abnormal loads may be detrimental to growth and development. Joint moments from an infant musculoskeletal model could help assess pathologies such as developmental dysplasia of the hip (DDH). Previous computational studies involving infant biomechanics [2, 3] lacked the modeling of active muscle response which may affect musculoskeletal development [4]. As such, the purpose of this study is to create a preliminary musculoskeletal infant model that considers the muscle response to quantify hip joint moments.

METHODS: The test subject for this study was a healthy 2.4-month-old infant, 56 cm tall and weighing 5.35 kg. The subject was instrumented with reflective markers placed on the lower extremity and around the cranial to capture kinematic data using the VICON Nexus motion capture system. During the recording of this trial, the subject was able to move freely performing spontaneous kicking motions. OpenSim's generic GAIT 2392 musculoskeletal model was scaled as seen in Figure 1 using the kinematic data recorded. A point force, representing the weight of the subject in the normal direction, was applied to the pelvis and an inverse dynamics problem was solved for joint moments.

RESULTS: Ranges of motion and joint moments during hip flexion and abduction are presented in Figure 2 and 3. Model scaling and kinematics were compared to experimental data while joint moments were compared to literature [5]. The hip flexion to extension (1.25 ~ 1.6 s) is seen in Figure 2a. The hip joint flexion moments shown in Figure 2b are consistent with the ranges of motion seen from hip flexion to extension during the trial. Similarly, Figure 3a shows increased hip abduction during hip flexion (1.25~1.5s) which may be influenced by the external rotation seen as the hip flexes. Hip adduction increases during hip extension (1.5~1.6 s) which may be influenced by the internal rotation as the hip goes into extension at the end of the kick cycle. The hip joint abduction moments shown in Figure 3b are consistent with the ranges of motion seen from hip abduction to adduction during the trial.

DISCUSSION: Our computational model proposes a novel solution to study infant biomechanics in a non-invasive manner while considering both active and passive muscle response. The validation of the scaled model comes from comparing the upper segment and lower segment (USLS) ratio. The USLS ratio of the scaled subject was 1.61, comparable to the average USLS ratio of 1.7 at birth [6], which decreases as the infant ages. Joint moments from our model show reasonable agreement with previous studies [5] despite the complex forces that produced an spontaneous kick. One limitation of this study was the lack of force plate data of the subject during its movements. This was the primary cause of Opensim calculating the joint moments using a constant point force representing the weight, which caused the abundance of noise in the joint moment calculations. In the future, we plan to classify spontaneous kicks based on intensity and range of motion and to quantify individual muscle contributions, allowing comparison of joint moments and internal muscle forces across infant populations. Our model lays the foundation for a musculoskeletal framework that can potentially be used to appropriately quantify and understand movement control and biomechanics of the hip joint in healthy infants and those with DDH or other orthopedic conditions.

SIGNIFICANCE/CLINICAL RELEVANCE: (1-2 sentences): To our knowledge, this is the first musculoskeletal model that aims to quantify physiological hip joint moments in infants. Development of a valid musculoskeletal model of an infant hip may be a useful tool in understanding and improving infant hip health.

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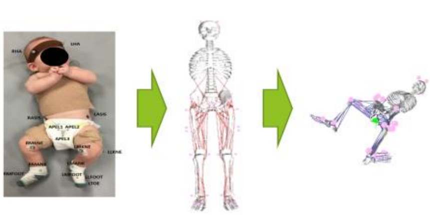

Figure 1. Infant musculoskeletal model workflow

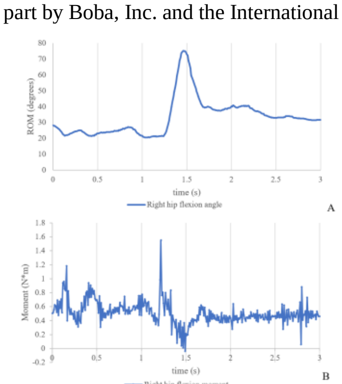

Figure 2. (a) Right hip flexion ROM, (b) Right Hip flexion moment

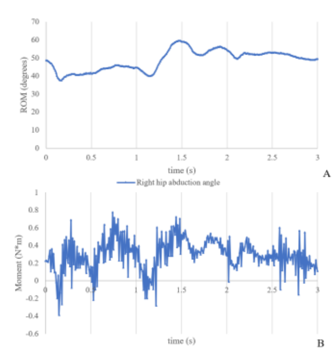

Figure 3. (a) Right hip adduction ROM, (b) Right hip adduction moment