INTRODUCTION: Developmental dysplasia of the hip (DDH) is commonly characterized by an altered acetabular geometry, which results in insufficient coverage of the femoral head, altered loading of the intra-articular cartilage [1], and increased risk for hip osteoarthritis (OA) [2]. In an effort to reduce symptoms and prevent or delay the onset of hip OA, periacetabular osteotomy (PAO) surgery is performed to reorient the acetabulum to provide more complete coverage of the femoral head [1]. Although effective at improving short term pain and physical function, long-term reports indicate a joint-survivorship rate of only 29% after 30 years [3]. One potential barrier to optimizing long-term joint survival could be that a precise understanding of how PAO reorientation alters muscle-driven joint loading has not been established. Furthermore, although the classic description of DDH includes general anterolateral deficiency, it has recently been shown that insufficient femoral head coverage within this population is much more heterogeneous, and includes anterolateral, global, and posterolateral deficiencies [4]; yet the differing effects of PAO on joint loading across subgroups remains unknown. Probabilistic analyses are robust statistical tools that provide comprehensive assessment of the effect of input perturbations on biomechanical outputs [5]. Therefore, our objective was to identify the difference in sensitivity of muscle-driven hip loading to PAO reorientation across two subgroups of DDH within a probabilistic framework.

METHODS: With university Institutional Review Board approval and written informed consent, MRI (psosas origin to knee joint) and gait data (whole-body kinematics and ground reaction forces) were collected from two female patients (DDH1 and DDH2) diagnosed with symptomatic and radiographic DDH (lateral center edge angle < 20°). Three-dimensional reconstructions of the pelvis and bilateral femurs were generated from MRI (Amira). Each patient was classified within a DDH coverage subgroup based on differences in acetabular coverage in four anatomical regions of the femoral head compared to six age-matched asymptomatic hips (Fig. 1a) [6]. Each patient walked at their self-selected speed on an instrumented treadmill (Bertec) and one gait cycle from the symptomatic limb was used for analysis. An existing musculoskeletal model was modified by including subject-specific pelvis and femur geometries, hip musculature origin and insertion sites, and validated using established methods [7]. Simulated PAO was accomplished by including three additional degrees of freedom of the acetabulum relative to the femoral head to simulate acetabular extension, adduction, and medial translation reorientation (Fig. 1). Two-thousand Monte Carlo (MC) simulations were performed per patient to assess the sensitivity of hip joint reaction force (JRF) across the gait cycle to PAO reorientation. Within each MC iteration, PAO orientation was randomly sampled from an existing database of post-surgical PAO reorientation angles [8]. 99% confidence bounds were used to estimate the range of peak JRF in early and late stance (JRF1 and JRF2). Sensitivity factors between peak JRF (JRF1 and JRF2) and PAO reorientation were calculated using Pearson correlation factors (strong: r ≥ 0.75).

RESULTS: DDH1 demonstrated anterolateral deficiency and DDH2 demonstrated posterolateral deficiency (Fig. 1b). For DDH1, simulated PAO had a greater influence on the superoinferior (S/I) JRF than on the anteroposterior (A/P) or mediolateral (M/L) JRF. Contrarily, simulated PAO for DDH2 had a greater influence on the A/P JRF, as indicated by the confidence bound sizes (Fig 3a). At JRF1, A/P, S/I and resultant JRFs of DDH1 were strongly sensitive to acetabular extension (r = 0.87, 0.92, 0.92), while the M/L JRF of DDH2 was strongly sensitive to acetabular adduction (r = 0.81) (Fig. 3b). At JRF2, the A/P JRF of DDH1 was strongly sensitive to acetabular extension (r = 0.89) and the M/L JRF was strongly sensitive to acetabular adduction (r = 0.75); the S/I and resultant JRF of DDH2 were strongly sensitive to acetabular extension (r = 0.87 and 0.77) (Fig. 3b).

DISCUSSION: A probabilistic analysis was used to assess the sensitivity of muscle-driven hip joint loading to simulated PAO reorientation in two types of patients with DDH. Of particular interest was the difference in influence, timing, and direction of sensitivity of simulated PAO on joint loading between patients due to differences in their coverage deficiencies. For DDH1, demonstrated acetabular coverage consistent with the classic description of DDH (anterolateral coverage deficiency), hip JRF was strongly sensitive to acetabular extension reorientation throughout the entire gait cycle (i.e. hip JRFs were reduced in DDH1 as acetabular extension was increased). However, for DDH2, who demonstrated coverage patterns consistent with acetabular retroversion (posterolateral deficiency), hip JRF was strongly sensitive (reduced) to acetabular adduction reorientation during early stance and acetabular extension reorientation during late stance. These differences are likely largely attributed to differences in contributions of muscle force generation, primarily the rectus femoris (RF). Reorienting the acetabulum results in altered active length and line of action of muscles that originate within this region (e.g. RF), which directly influences a muscle’s ability to produce force and alter joint loading [9]. Because muscle force generation is also affected by bony morphology, the role of muscle contributions to joint loading should be considered in future PAO analyses of various DDH subgroups.

SIGNIFICANCE/CLINICAL RELEVANCE: Identifying the differences in sensitivity of joint loading to PAO reorientation within two subgroups of DDH [6] is relevant to understanding patient-specific optimal alignment in the context of joint loading. In addition, understanding how PAO reorientation affects the muscle function differently dependent upon bony morphology can be used to provide more targeted post-surgical interventions.

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