Hip Joint Reaction Force Contributions to Acetabular Edge Loading in Dysplastic Hips: A Subject-Specific Musculoskeletal Modeling Study

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BACKGROUND

- Acetabular labral tears
  - Common in developmental dysplasia of the hip (DDH)[1]
  - Expedite hip joint degeneration & osteoarthritis[2]
- Mechanical role of labrum
  - Constraint at acetabular edge to stabilize hip joint[1]
- DDH: abnormal hip anatomy[3]
  - Shallow acetabulum; poor femoral coverage (**Fig. 1**)
  - Loading at acetabular edge may alter labral tear risks

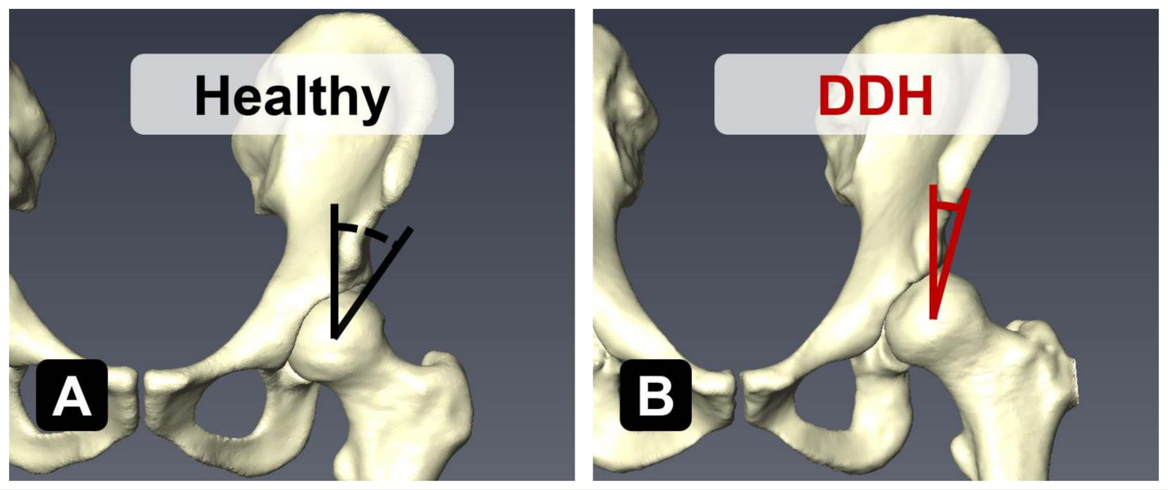

Figure 1. Pelvis and proximal femur anatomy of (A) a healthy adult and (B) a DDH patient, with poorly covered femoral head in contact with the edge of the shallow acetabulum.

- Acetabular Edge Loads
  - Depend on anatomy & hip joint reaction force (HJRF)
  - Cannot be measured in-vivo
- Computational modeling strengths & limitations
  - Finite element models for labral stresses in DDH[4]
    - Detailed anatomy; HJRF not specific to individual
  - Musculoskeletal models (MSM) for edge load risks in hip prosthetics[5]
    - Individualized HJRF estimates; generic anatomy cannot precisely inform loads on natural acetabula
- HJRF contribution to acetabular edge loading in DDH (vs. healthy) is unknown

OBJECTIVE

Compare acetabular edge loading during gait between DDH and healthy hips by quantifying subject-specific HJRFs and their projections onto the acetabulum

METHODS

- 18 subjects with informed consent:
  - 9 **Healthy** (6F, 26±4 y/o, 23.8±4.5 BMI)
    - No hip radiographic deformity; random leg
  - 9 **DDH** (6F, 26±7 y/o, 22.7±3.1 BMI)
    - Deformity confirmed by radiograph; affected leg
- Barefoot gait data collected using 23 markers, 10 cameras, 4 force plates, and low-pass filtered[6]
- Subject-specific pelvis and proximal femur anatomy reconstructed in 3D from CT images[6]
- 3D anatomy imported to an OpenSim model with 96 muscles and used to update muscle paths in each subject-specific MSM (**Fig. 2**)
  - HJC moved to CT femoral head centroid, assumed fixed in location (i.e. rotation-only hip joint)
- HJRF during a representative gait cycle computed from MSM-estimated muscle forces (static optimization)
  - HJRF defined as force vectors from HJC (**Fig. 3**)

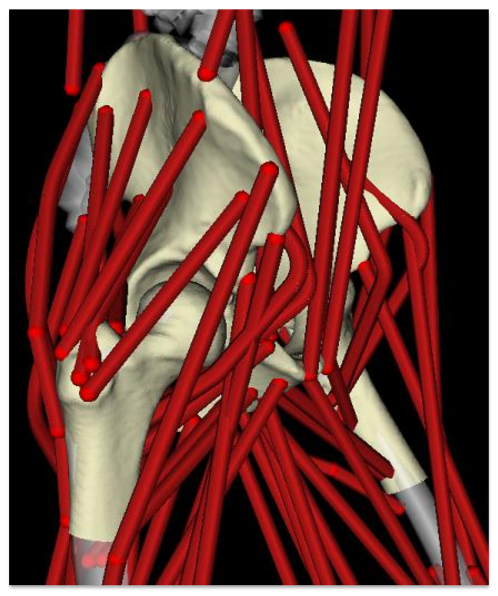

Figure 2. Subject-specific MSM with CT-based hip anatomy, updated muscle paths and HJC locations.

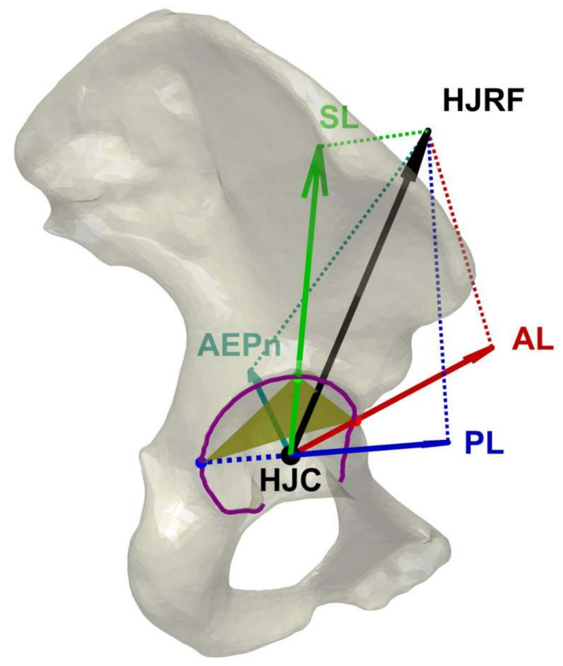

Figure 3. Diagram of the edge (purple), AEP (gold), HJRF projected in AEPn, AL, SL, PL directions on acetabulum. (HJRF shown depicts late-stance hip loads, directed *away* from PL.)

- Acetabular edge load estimation: (**Fig. 3**)
  - i. Acetabular rim divided into 3 regions
    - Antero-lateral [**AL**]: near anterior inferior iliac spine
    - Supero-lateral [**SL**]: highest point on the rim
    - Postero-lateral [**PL**]: most posterior point on the rim
  - Edge Load Direction = vector from HJC to AL/SL/PL
  - Closeness to Edge = angle from HJRF to AL/SL/PL
  - Edge Load = force projected by HJRF to AL/SL/PL
  - ii. Acetabular edge plane [**AEP**]
    - Approximated border of femoral coverage
    - Fit points on the rim to a plane
    - Normal [**AEPn**] = compression direction (to medial)
  - Joint Compression = HJRF projection to **AEPn**
  - Femoral position in acetabulum = HJC-**AEP** distance
- **DDH** vs. **Healthy**: angles, forces, HJC-AEP distance
  - 2-tailed independent-samples *t* tests (α=0.05)

RESULTS

- **DDH** (vs **Healthy**) had higher HJRFs (5.6 v 4.7 ×BW)
- **DDH**: larger HJC-AEP distance (9.8 v 4.7 mm, *p*=.005)
- **DDH**: smaller angle to AEPn/AL/SL ($p\leq$.049; **Fig. 4ACE**)
- **DDH**: higher AL/SL edge loads ($p\leq$.036; **Fig. 4DF**)

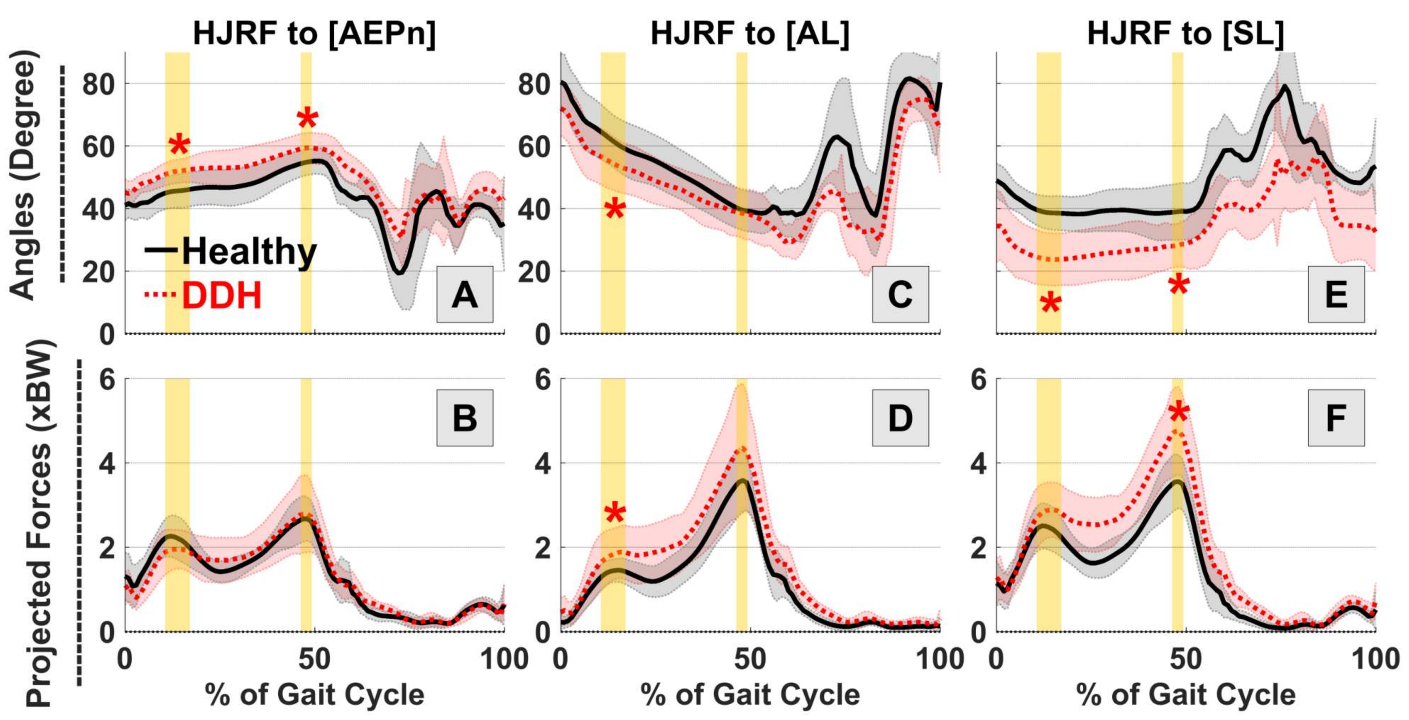

Figure 4. Angles (top) and forces (bottom) from HJRF to AEPn (left), AL (middle), and SL (right) on acetabulum over a gait cycle. *t*-tests performed at the 2 times of HJRF peaks (highlighted in yellow); * = statistical significance.

DISCUSSION

- Higher hip loads on DDH acetabula could be related to poorer femoral coverage, i.e. larger HJC-AEP distance
  - Altered HJC location & muscle paths affect HJRF
- DDH acetabula with high angles of inclination shifted joint compression direction (AEPn) to be less superior
  - Higher HJRF required to compress & stabilize the hip
- Shallow acetabula cause the edge to be closer to HJRF
  - Higher loads projected by HJRF to AL/SL edges
  - Edge loads significantly elevated in gait phases with high HJRF magnitude (e.g. late stance push-off)
- Effects of HJRF & anatomy are coupled: high HJRF or shallow acetabula does not always increase edge loads
  - Treatments to target anatomy (via surgery) or HJRF (via rehabilitation) could both help reduce edge loads

SIGNIFICANCE

- Analyzing DDH-specific HJRFs in context with detailed acetabular anatomy may help clarify the morphological and mechanical risk factors for labral tears in DDH hips
- Findings support concept of higher edge loads in DDH and provide novel subject-specific analyses of HJRF that can inform surgical or rehabilitative interventions to reduce edge loads and manage labral tear risks

REFERENCES

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