Introduction

- Femoroacetabular impingement (FAI) and acetabular dysplasia are two pathoanatomical conditions of the hip, and these conditions may be the primary factors leading to osteoarthritis (OA).

- FAI: Restriction of motion caused by osseous deformities, most often sub-grouped into those of the femur (cam), acetabulum (pincer), or both (mixed)[1].

- Acetabular dysplasia: Characterized by an under-contained hip where poor coverage of the femoral head by acetabulum induces excessive motion and overloading of cartilage.

Figure 1. (A) Cam FAI: Characterized by bony prominence of anterolateral femoral head; (B) Pincer FAI: Prominence of anterior acetabulum; (C) Mixed FAI: Combined pincer cam impingement.

Figure 2. (A) Normal Hip: Well covered hip joint with stable femur head; (B) Dysplastic Hip: A “shallow” socket that inadequately covers the femoral head.

Objectives

- Integrate ShapeWorks with FEBio to enable flexible and robust analyses of shape and function.

- Quantify the variation in femoral head anatomy and acetabular rim coverage among normal hips and hips with cam/pincer/mixed type FAI.

- Examine the relation between shape and mechanics in a population of patients with hip dysplasia.

Statistical Shape Modeling (SSM)

- SSM quantifies complex anatomy and variation within and between populations of interest extracted from 3D image data[2].

- In SSM, each member of a population is represented by a dense set of correspondence points. Subsequently, statistical analysis is done on the vectors resulting from those point sets.

- ShapeWorks: Software for SSM developed within SCI [2,5].

Finite Element Analysis (FEA)

- FEA predicts patient-specific tissue mechanics [3,4].

- It’s a numerical technique for finding approximate solutions to boundary value problems for differential equations.

- FEBio (Finite Elements for Biomechanics): A nonlinear implicit FE framework [6].

- FE Model
  - Cortical bone: Discretized into triangular shell elements with position dependent thickness and is represented as linear elastic.
  - Cartilage: Discretized into hexahedral elements and is represented as neo-Hookean hyper-elastic.

Figure 3. An illustration of the basic concepts the ShapeWorks point-based correspondence optimization.

- Analysis will be performed on CT arthrography (CTA) images of the hip for 50 subjects per group to account for multiple groups (cam/pincer/mixed/normal).

- The output from SSM will be analyzed to understand morphological variability and improve mechanical models for FEA.

Figure 4. Shape variations captured in 3 modes: (0) Normal Mode; (1) Medial offset of the femoral head with respect to the posterior slip; (2) Size of femoral head; (3) Curvature of the trochanter.

Figure 5. (A) Color map for cortical bone thickness; (B) FE model of human hip in Preview.

Figure 6. Color map of total effective stress in PostView.

Figure 7. (A) Initial mesh; (B) Scaled mesh with half the number of nodes; (C) Scaled mesh with high density at regions with high curvature; (D) Scaled mesh with high density at areas of interest.

Discussion

- Two levels of analysis. First, comparison of all three subgroups of FAI (cam/pincer/mixed) as a single population to the normal subjects. Next, comparison between each sub-group.

- Determine the clinical metrics predictive of FAI related deformities.

- Identify the anatomical variation between normal and dysplastic hips.

References


Acknowledgments

Financial support from National Institutes of Health (R01GM083925 & R01EB016701)