RAPID COLLISION DETECTION TECHNIQUE IN THE EVALUATION OF FEMOROACETABULAR IMPINGEMENT

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INTRODUCTION:

In the native hip joint, Femoroacetabular Impingement (FAI) is also recognized as a cause of hip arthritis. Correction of the underlying structural abnormality permits the patient to regain a painless functional range of motion. A 2D approach to find an abnormality by checking alpha and beta angles [1] has been used. In cam type impingement where the femoral head is aspherical, recontouring of the femoral head neck junction restoring head sphericity has been shown to improve clinical function by means of both open and arthroscopic techniques. However, the less invasive techniques are more difficult in respect to accurately and reproducibly correcting the femoral head/neck deformity. More importantly, what represents a pathological head/neck deformity has not been fully delineated as well as the pathomechanisms of FAI which lead to joint deterioration.

Recent joint simulation studies using CT based HIP motion data have shown that patients with FAI have decreased flexion, internal rotation and abduction compared to normals [5]. While this information may be a useful tool in decision making as well as surgical planning for computer assisted surgery, this technique cannot account for cartilage strain which ultimately will lead to its deterioration.

The purpose of our study is to determine the feasibility of performing a rapid collision detection technique of the native hip joint using a patient based CT dataset in order to evaluate FAI. We present a rapid 3D system to rapidly detect impingements and compute and visualize approximate strain..

METHODS:

Computer tomography data of the hip joint as well as motion analysis data using a 3D Vicon analysis were collected from a patient suffering from FAI. For the motion analysis, seven VICON MX-13 cameras (VICON, Los Angeles, Calif.) at 200 Hz with retroreflective markers placed on anatomical landmarks were used. These data was then used for simulating the collision.

Like the common collision detection approaches, our solution [2] used two major algorithms: (i) Rapid Spherical Sampling (RSS) based on the fact that ball-and-socket joints, such as hip joint, are near-spherical objects (**Figure 1**). Our RSS samples the 3D mesh geometric information of the joint based on Spherical Coordinate System. The mesh is first mapped to 2D Spherical Coordinates with the distance data from the origin and then the distances of densely sampled points of the mesh surface are directly interpolated from ones of the triangle vertices through polygon rasterization. Then we use a large Lookup Table (LUT) [3] to maximally preserve the model's geometry information using the distance field. (ii) Rapid Spherical Impingement Detection (RSID): the collision detection is instantly processed by testing how near the target point is compared to the distance field in LUT. It directly provides the approximate strain measurement on the surfaces of the ball-and-socket joint.

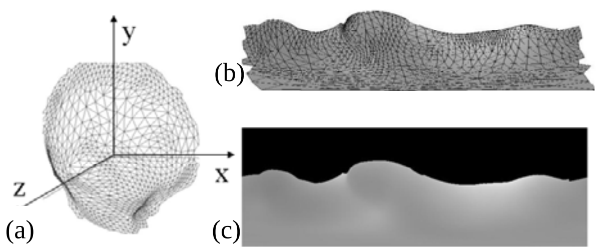

Figure 1: RSS: a) Socket in the Cartesian coordinates; b) The socket mesh mapped to the 2D Spherical coordinates; c) The mesh sampled.

All tests were conducted using an AMD Opteron Processor 252 at 2.6 GHz with 2GB of memory. Both our geometric representation (preprocesisng) and collision detection (simulation) were done in real-time and the accuracy was sufficient where the sampling precision can reach 0.05° or higher in real-time with an affordable memory cost.

RESULTS:

Color scales are used to illustrate the distances between the ball and socket, to appoximately represent the strain distribution without increasing any extra computation cost. Many collision deteciton algorithms such as RAPID [4] usually require extra functions to measure the distance information. In Figure 2, the 12K-triangle model is segemented from CT data (1.25*mm* thickness, resolution of 512*512).

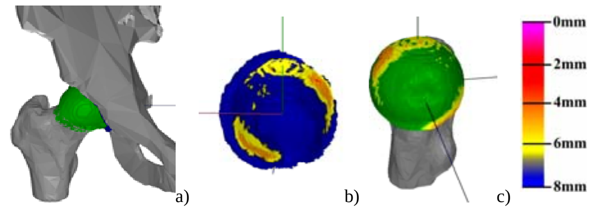

Figure 2: The strain distribution: a) the right hip joint, anterior view; b) the socket, right lateral view; c) the femur, left medial view.

The system can be also applied to the range of motion (ROM) simulation to study the impact of the abnormal spherical joints causing impingement during motions. **Figure 3** shows the impingement under the observed ROMs with Abduction 48.7°, Internal rotation 5.6° and Flexion 103.1° measured in real-life motion capture session.

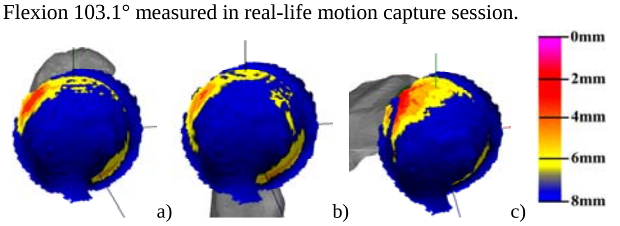

Figure 3: Impingement results under the observed ROMs, right hip joint from left medial view and the pelvis (except the blue socket region) not visualized: a) Abduction; b) Internal rotation; c) Flexion.

DISCUSSION:

Our rapid collision detection and proximity visualization system is suitable for detecting impingement based on geometric shape for any ball-and-socket type joint. This information will also aid in a better understanding of the pathomechanism of impingement of the native hip joint in terms of what factors other than severity of deformity lead to cartilage degeneration. More importantly, this information can be used in computerized surgical planning tools for the treatment of FAI.

Future work will be required to translate the distance between the two surfaces into cartilage strains. Various cartilage thicknesses and deformation parameters on the surfaces can be saved in a table to adapt to the impingement areas. Then, in the range of motion observation we can consider a distance offset to represent the different thickness of the cartilage.

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