SIMULATING THE EFFECT OF FAI SURGERY ON HIP KINEMATICS

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INTRODUCTION

Femoroacetabular Impingement (FAI) is a clinical condition characterized by an early abnormal contact between the femur and the acetabulum during hip joint motion often observed in flexion combined with internal rotation. Clinical problems associated with FAI include structural damage to the labrum and cartilage all of which may eventually lead to development of Osteoarthritis. The surgical treatment of FAI, described by Ganz et al.[1], comprises mainly of removal of regions on the femoral neck such as abnormal bumps on the bone that are believed to cause early femoroacetabular interference. The amount of bone removal is a compromise between maximizing bone removal to minimize interference and minimizing bone removal to maintain maximum bone strength and integrity. This optimization process is difficult to achieve at the time of surgery. Therefore there is a need to pre-plan the surgery to optimize bone resection in order to restore normal interference free motion with minimal decrease in bone strength. Therefore, the long-term goal of this study is to: 1. develop an image-based, subject-specific, three dimensional model of the hip to study the relationship between the amount and location of bone removal and the ROM and femoroacetabular interference pattern, and 2. the relationship between bone removal and the changes in bone strength and its load carrying capacity. The goal of this study is to achieve the first part of this long term goal. Three dimensional models were used in the past to study the range of motion of the hip [2]. However none of these models could predict the effect of bone removal on joint kinematics and end of range bone-to-bone interference pattern.

METHODS

This study was performed on CT data obtained from two normal subjects and two patients diagnosed with FAI. Simulating the FAI surgery involves 4 main steps:

1. Image Processing: The 3D models of the bones were generated by the process of segmentation followed by three dimensional rendering using Analyze Direct^{TM}. Segmentation is the process of extracting the boundaries of each bone in each two dimensional slice (Figure 1). Three dimensional rendering is the process in which the set of two dimensional bone boundaries are combined to create a three dimensional representation of the bone (Figure 2).

2. Identifying the center of rotation of the hip joint: The center of rotation of the hip joint is computed by optimally (in the least-error sense) fitting spheres to the femoral head and to the acetabulum. The average of the location of the centers of these spheres was used as the location of the center of rotation of the joint (figure 3).

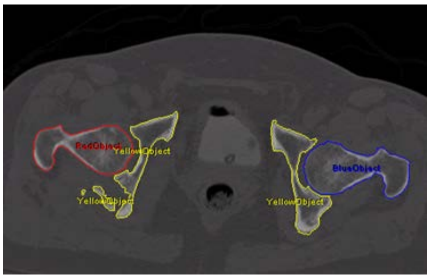

Figure 1: Example of the segmentation process used to obtain the contours of the bones in each 2-D slice.

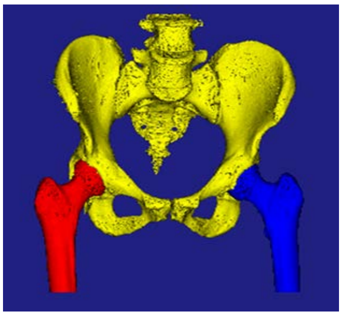

Figure 2: Three dimensional rendering to obtain a three dimensional representation of the femurs and the pelvis.

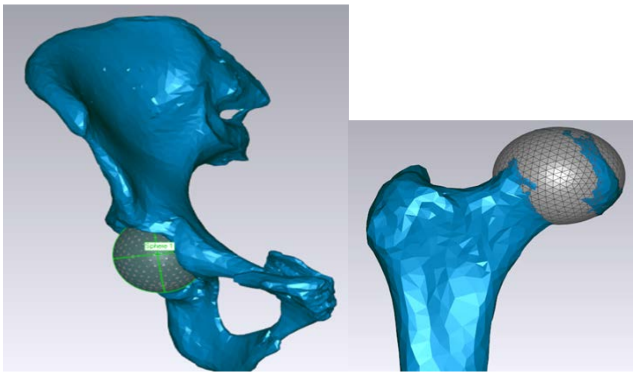

Figure 3: Locating the center of rotation of the hip joint by optimally fitting speheres to the acetabulum and to the femoral head

3. Simulating hip kinematics and Femoroacetabular interference: Simulating the kinematics of the joint was performed in ADAMS^{TM} by producing movements of the femur relative to the acetabulum in different directions through rotations about the previously defined center of rotation. Movement in a specific direction was continued until bone-to–bone contact prevented further motion. The contour of bone-to-bone contact was then marked on the femur and on the acetabulum. The simulation process demonstrated in this study consisted of positioning the hip at 90 degrees of flexion and moving gradually into internal

rotation until bone-to-bone interaction prevented further movement (Figure 4). This simulation process was used to mimic the clinical test often used for diagnosis of FAI in which the hip is positioned in 90 degrees of flexion followed by internal rotation to the point where pain is elicited.

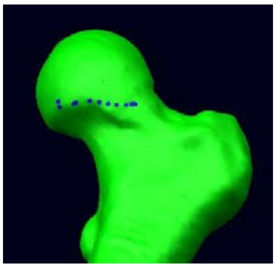

Figure 4: Image of the femur showing the points of bone-to-bone interference corresponding to 90 degrees flexion followed by internal rotation.

<u>4. Correlating bone resection with changes in kinematics and bone-to-bone interference:</u>

Removal of regions of the femoral neck (Figure 5) was performed in Geomagic™, a reverse engineering software. Also in Geomagic™, clinical parameters that are often used to assess presence of FAI [3] could be obtained (Figure 6). Specifically, one major clinical parameter used for this assessment is the alpha angle [4] defined as the angle between a line drawn from the center of the femoral head through the center of the femoral neck, and a line from the center of the femoral head to the femoral head/neck junction, found by the point by which the femoral neck diverges from a circle drawn around the femoral head (Figure 6). The simulation process described above was then iteratively repeated until the impingement range was returned to normal values and the alpha angle was reduced to be within a normal range which is defined as less than 55^0 [4].

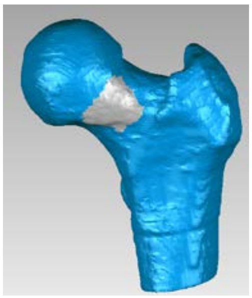

Figure 5: Image of the proximal femur showing the region removed from the femoral neck(grey colored region).

Figure 6: Definition of the alpha angle from a two dimensional slice through the bone model performed in Geomagic™

RESULTS AND DISCUSSION

Comparing the ROM in internal rotation starting from a flexion angle of 90 degrees shows the ROM of the pathological hips with impingement to be less than those for the normal hips by about 5 degrees. Also the alpha angle for the pathological hips (83.7^0 and 92.7^0) was about twice as large as for the normal hips (40.4^0 and 42.2^0) (Figure 7). By iteratively removing bone from the femoral neck in the region were impingement was observed (Figure 5), it was possible to reduce the alpha angle back to normal range from 83.7^0 to 42^0, and to reduce the impingement region to resemble that of the normal hips (Figure 7).

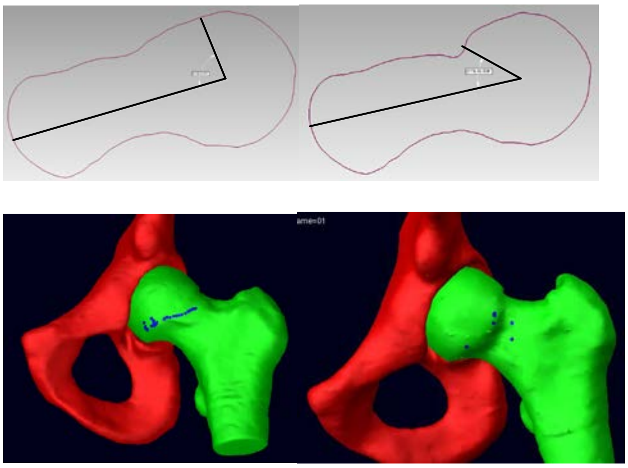

Figure 7: Impingement before (left) and after (right) the computerized surgical process along with the corresponding change in the alpha angle (above).

CONCLUSIONS

The Process described in this study of creating image-based subject specific 3D models of the bone structure of the human hip followed by kinematic Analysis of FAI interference pattern may provide a useful pre-planning surgical tool to assist the surgeon in determining the location and the amount of bone removal necessary to restore interference-free normal function. Future studies will further investigate the effect of bone removal on the strength and load carrying capacity of the bone so that the amount of bone resection could be selected such as to minimize the loss of bone strength while reducing abnormal femoroacetabular interference.

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