The CT-Based Patient Specific Hip Joint 3D-Modeling; Potential to Correct the Alignment

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ABSTRACT

Background: The salvage proximal femoral osteotomy is performed in mild or moderate osteoarthritis when the articulating surfaces are normal and relieves the subject's pain. Because the importance of angular mal-alignment of the femur bone at the hip junction accurate pre-op planning based on patient specific anatomy is required to prevent any lower limb misalignment and joint problem pre-operative.
Methods: In this study a CT-Based modeling technique was used to generate a 3D model of the patient's hip and proximal femur. The registration stage using angio-fluoroscopy was performed to calculate the proximal femur kinematic and input it into a finite element model to achieve the stress distribution pattern of femuroacetabular joint.
Results: From finite element model the stress distribution on the articulating surface at the contact zone was analyzed. The result was showing the maximum stress of 1.1 MPa at the contact surface where femur contact the acetabulum. The maximum stress is found in line with mechanical loading of the lower limb.
Conclusion: Use of a non-invasive 3D modeling method will remediate the surgical approach in pre-op stage. The in-vivo modeling and assessment of the patient femoroacetabular contact has performed. It has been shown that the accuracy of the proposed model is comparable with the existing surgical pre-op planning.

Keywords:

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INTRODUCTION

As it was seen in previous research,the mechanical strength of the hip is dependent on the shape and structure of the bone[1-4]. This can be examined using a finite element (FE) method. The FE method has shown promising results for the clinical assessment of hip strength[5]. Timo et al. were created a method generating 3D FE model of the hip from 2D radiographs[6].

FEM-supported femur model was developed with and without hip prosthesis by many authors[7]. Huiskes (1982) wrote already about one main problem of all femur FEM—the inhomogeneous material properties of human bone with the difficulty to integrate them accordingly to the Hook law in the FEM model[8].

This study is aiming to present a patient specific model for the hip and investigate the mechanical behavior of the hip joint at its contact surface while it is at full flexion. The study is going to present a 3D FE modeling which can be used for pre-op planning of an osteotomy corrective surgery.

MATERIALS AND METHODS

The 3D anatomical geometry of the bones of an osteoarthritic right hip of a 24-year-old male was generated using the data obtained from CT scan (General Electric Medical System, Light Speed). The data was created with a 2.5 mm slice thickness precision. The right hip bones model was created in Mimics 10.01 software (Materialise NV) from 178 CT data set slices[9]. An appropriate threshold limit was applied to recognize the hip components from the gray scale CTimages then asegmentation process was performed[10,11]. A boolean operation was performed to allow separation between the proximal femur and the pelvis as shown in Fig 1-a, b.

In order to mesh the created 3D models and repair the possible irregularity of the models, they were imported to Solid Works 2014 (Simulia Dassault Systems). The irregular surfaces were smoothed locally or in general, and an appropriate mesh was performed on the model as it is seen in Fig 2-a,b. The model then was exportedin parasolid format. The right hip 3D geometrical model was imported into the commercial finite element code Abaqus software 6.10 version (Simulia Dassault Systems). The bones were assumed to be rigid, assumed to be isotropic, with the elastic modulus of 750 (N/mm^2) and a Poisson ratio of 0.3.

In this study a virtual CT-Based modeling technique is used to create a 3D model for the patient's pelvis and proximal femur. The model was pre and post processed using the commercial finite element code Abaqus 6.10 (Simulia Dassault Systems). The bones were assumed to be rigid, and a total number of 478434 tetrahedral elements were used to mesh the bones. The boundary

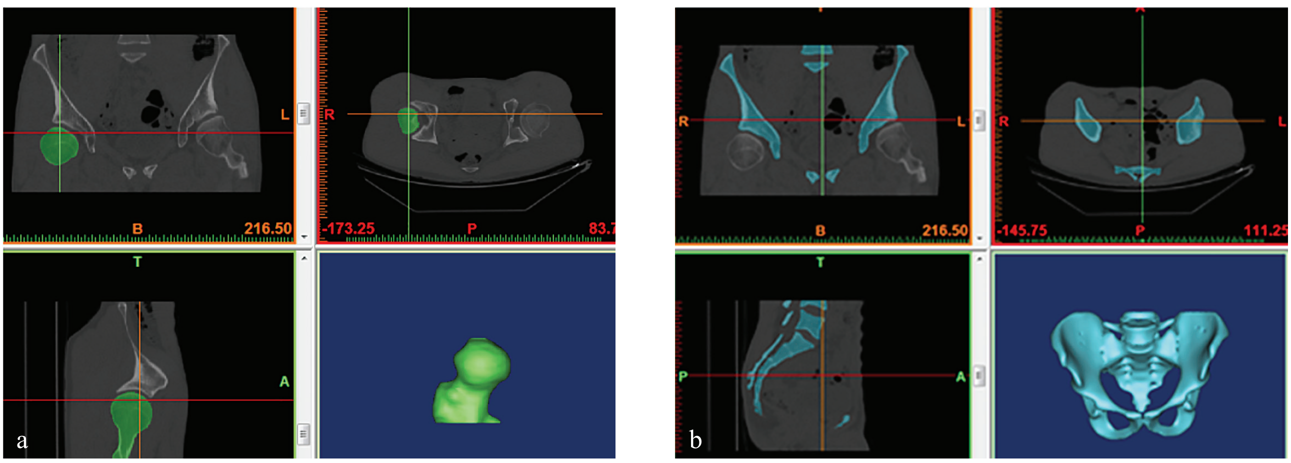

Figure 1. Right proximal femursegmentation (a), Pelvis segmentation (b)

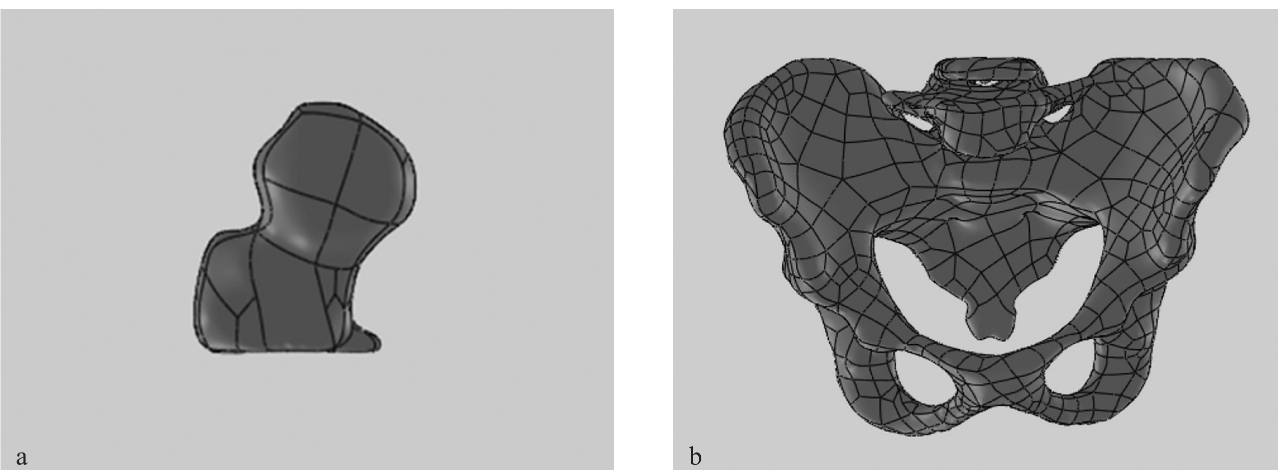

Figure 2. The scan to 3D for Proximal femur (a), Pelvis (b)

condition of 90 degrees flexion was assigned to the proximal femur. The center of rotation of the joint was defined using a best fit sphere into the femur head. The mechanical properties of the joint such as stress distribution was assessed through a path passing on the boundary of contact surface as shown in Figure 3. The results of the finite element model were analyzed in 20 different steps. As a result, typical stress distribution on the contact joint at step 18 is shown in Figure 4.

RESULTS AND DISCUSSION

From the finite element analysis performed in this study maximum stress of 1.1 MPa was found on the contact articulating surface. The result of the stress along the defined path has been shown in Figure 5. The maximum stress of 1.1 MPa was occurred almost at the top of the femur head as demonstrated in Figure 6.

To assess the biomechanics of the hip joint it is necessary to evaluate the mechanical properties of the joint at the contact zone. FE model also provides additional information on the stress profile of the contact surface when the joint moves from the full extension to full flexion.

The result of stress distribution on the hip joint articulating surfaces will help to assess the alignment of the lower limb. For instance, correction of the proximal femur alignment without paying attention to the stress distribution of the joint contact surface especially at weight bearing posture may lead an error to the osteotomy correction. The stress distribution at the femoroacetabular joint before any surgical approach may be a good reference to make a decision about the surgical corrective approach.

In the current FE model the femoral cartilage was not physically created as the aim was to show how this method can be useful for pre planning of an osteotomy correction. While the absolute numerical value when the articulating surface change but the methodology and approximation still can be used to guess the stress distribution on the contact surface.

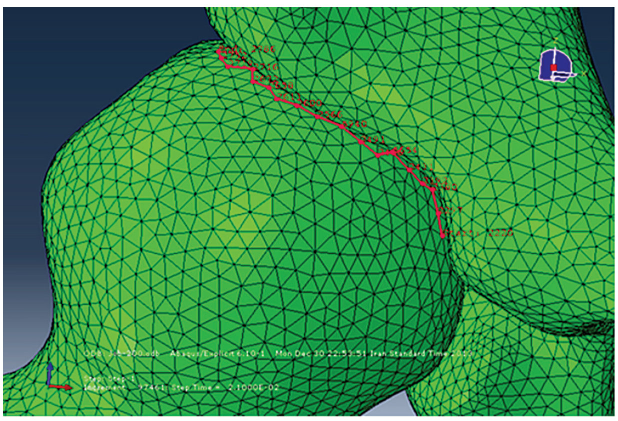

Figure 3. The path was defined on the proximal femoral head at contact zone boundary

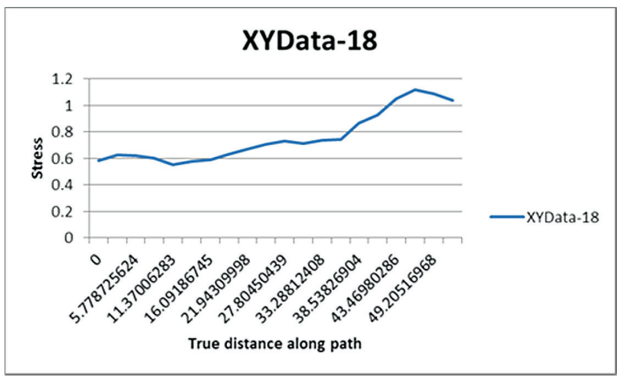

Figure 5. Stress distribution on the articulating surface along the path.The maximum stress was 1.1 MPa.

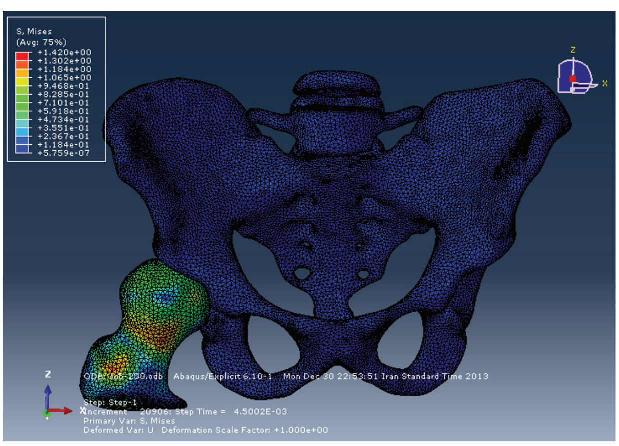

Figure 4. The femoroacetabularjoint contact stress distribution

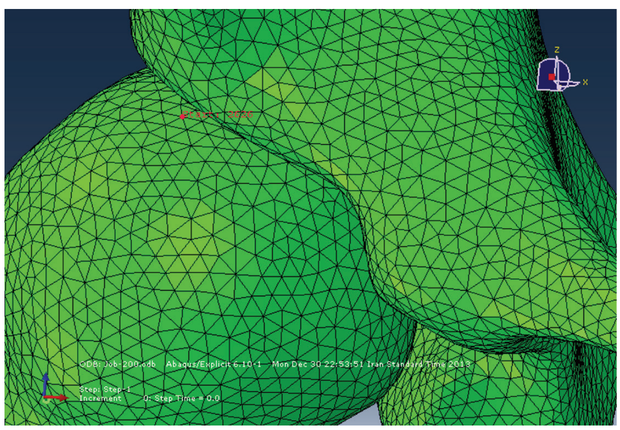

Figure 6. The point on the proximal femur path with the maximum amount of stress.

CONCLUSION

The in-vivo 3D assessment of the patient at the femoroacetabular joint can lead to a precision lower limb osteotomy correction. It has been shown that the accuracy of the proposed model is comparable with the existing surgical pre-op planning.

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