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ESTIMATION OF THE STRESS DISTRIBUTION IN A DYSPLASTIC HIP JOINT, A CASE STUDY PRE AND POST-OPERATIVE

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INTRODUCTION

Hip dysplasia is the main cause of pain in the hip joint in young and adult people and it is the major common cause of osteoarthrosis in adults [1,2]. Biomechanical analyses of the behavior of a pathological hip joint give us important personal information to planning a more adequate surgical process. Simulations of the operative process proposed by the Surgeon in order to decrease or eliminate the pathology, allow us to estimate the future stress distribution generated in the hip joint. The aim of this investigation was to obtain and compare the stress distribution on a dysplastic hip joint on three different scenarios: standing on two legs, single leg standing and the stance phase while normal walking. All this three scenarios were performed using finite elements analysis.

METHODS

The 3D pathological model was constructed from the CT scanning images of a 16-years-old female patient with residual dysplasia on her left leg. The patient had a Wiberg center-edge angle of 8±1º, an anteversion angle of 52±2º and an angle between the femoral shaft and the femoral neck of 150±3º (coxa valga). The CT images were obtained using a Scanner Toshiba/Aquilion 120 Kv and 39.5 mAs, with a number of slices of 71, pixel size of 0.782mm, slice thickness of 3mm and a resolution of 512 x 512. The 3D model was created by the reconstruction software from 2D DICOM data, INVESALIUS v3.0 [3]. The proximal femur and the acetabulum were meshed each one applying tetrahedral elements Tet4. Ranges of segmentation were used to assign three kinds of materials to the femur: cortical, trabecular and subchondral bone. Subsequently, el model was exported to the nonlinear finite element solver for biomechanics FEBIO v1.5 [4] (Figure 1). The pre-process of the model was developed using PREVIEW v1.7 [4] and the post-process with POSTVIEW v1.4 [4].

Two volumes with constant thickness (1±0.3mm) were incorporated to the model between the femur and the acetabulum with the mechanic properties of the articular cartilage. Femur was modeled as isotropic linear elastic and was segmented based on the densities obtained in the CT images [5]. Cortical, subchondral and trabecular bone were modeled with a Young´s Modulus of 14 GPa, 700 MPa y 1150 MPa respectively, additionally the Poisson´s ratio assigned were 0.29, 0.2 y 0.24 respectively. Articular cartilage was modeled as a homogeneous, isotropic, incompressible and Neo Hookean hyper-elastic material with a Young´s Modulus of 13 MPa and a Poisson´s ratio of 0.38. The acetabular region of the pelvis was considered as a rigid body to simplify the model.

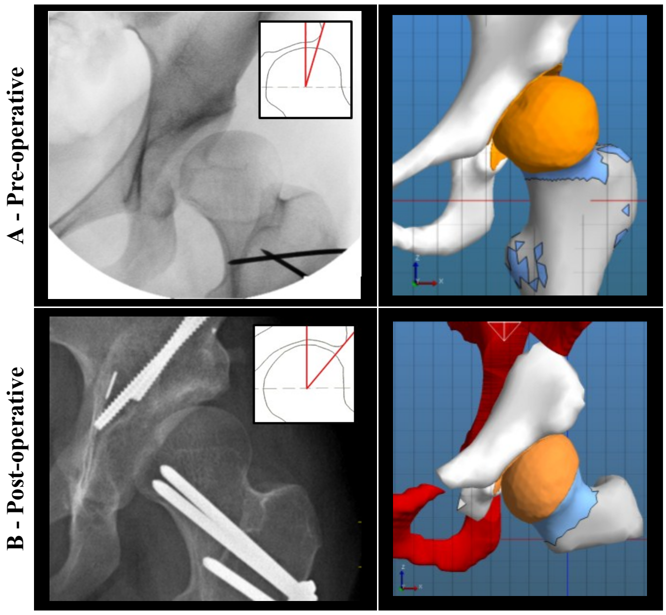

Figure 1: A - Radiography pre-operative. Finite elements model meshed and characterized. B - Radiography post-operative. Finite elements model of the joint relocation.

The contact surface between the acetabular cartilage and the acetabulum is the same to enable a smooth contact. Similarly, the femoral cartilage and the femoral head have a common surface to obtain an appropriate contact. The femoral base was constrained in two sections: on the outside of the diaphysis (distal femur) the movement was constrained in all degrees of freedom; and on the inside of the diaphysis the vertical movement was constrained. A slice contact between the acetabular cartilage and the femoral cartilage was defined and a tied contact between the femoral cartilage and the femoral head. On the standing on two legs simulation, a load L= 0.5 Weight body (WB) was applied on the acetabulum in a vertical direction. To simulate the one leg standing, we applied a resultant force L=2.2 WB which was obtained from the equilibrium equations established on a center point located on the femoral head [6,7]. We considered six muscles actuating in the equilibrium of the joint: gluteus medius, gluteus minimus, tensor fascia lata, rectus femoris, sartorius and piriformis. To simulate the stance phase of a gait cycle, we divided this phase in ten stages; on each step, the resultant force was applied according to the data suggested in [8], furthermore, the femoral rotation was considered in the sagittal, frontal and transverse plane [9].

The post-operative finite elements model was created based on the surgical process proposed by the orthopedic surgeon. A surgical cut to correct the femoral anteversion was developed at lesser trochanter level; a rotation of 20±2º was done on the transverse plane. Another surgical cut was developed on the pelvis to improve the covering of the femoral head. The relocation of the acetabulum consisted of a rotation of 15±2º on the coronal plane and a rotation of 2±0.3º on the transverse plane. The anteversion angle was reduced to 32±2º and the Wiberg center-edge angle increase to 27±2º. In the three cases, the resultant force was applied on the acetabulum in vertical direction. Stress generated on the femoral head was obtained on the pre and post models in the three scenarios.

RESULTS AND DISCUSSION

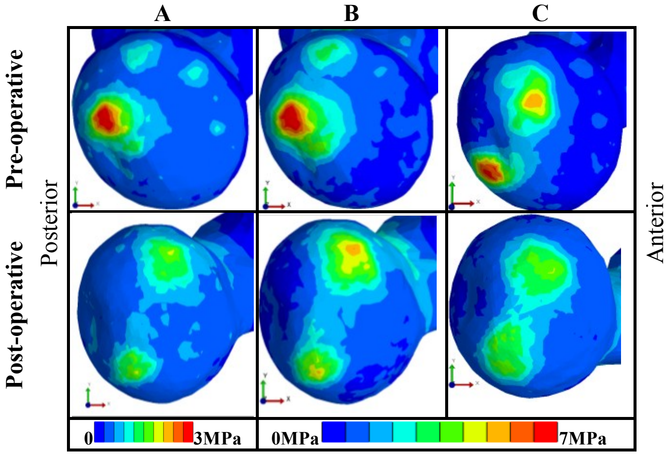

Figure 2: A - Effective Stress during standing on two legs. B - Effective stress on one leg standing. C - Effective stress during heel-strike in a gait cycle.

The results indicated that the pathological femoral head supports a considerably higher load than the post-operative model. During the simulation of the bipedal position, the stress generated on the femoral head is 43% lower on the post-operative model (Figure 2A). Similarly, on the simulation of the single leg stance, the stress generated in the post-operative model on the femoral head is reduced in 25% (Figure 2B). Figure 3 shows the curve of effective stress obtained during the simulation of the stance phase of a gait cycle; the point of maximum stress (20% stance phase) evidence a stress reduction of 20.2% in the post-operative model (Figure 2C); furthermore, the effective stress through the complete stance phase, is lower in the post-operative model. The location of the weight bearing area was displaced in posterior-anterior direction and the size of the area increased, improving the stress distribution on the femoral head. The stress values obtained in this study are in the ranges presented in the literature. To simplify the model, only six muscles [6] was taken into account into the equilibrium equations in the center of the femoral head, besides, the lateral and frontal components of the resultant force were not considered. In the gait cycle, we took into account the angular changes of the femur of an asymptomatic person and the slight rotation of the pelvis was not considered [9]. We attempted to maintain a smooth contact between the bone and cartilaginous component; although there were some irregularities between the cartilages, it did not represent a significant factor in the results.

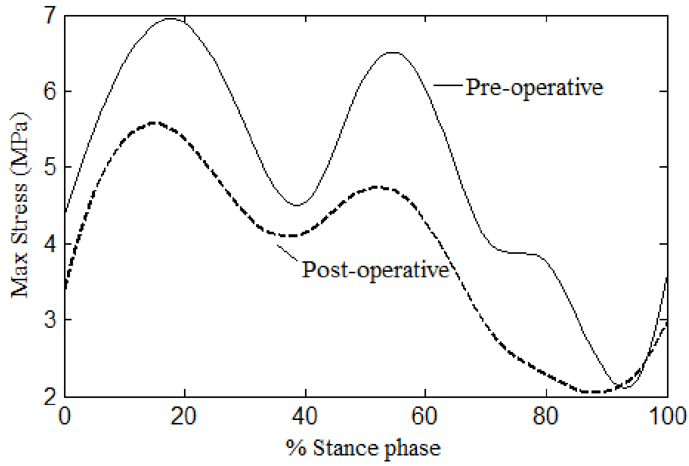

Figure 3: Effective stress generated on the femoral head during the stance phase of a gait cycle.

CONCLUSIONS

This study developed a subject-specific model of finite elements to estimate the stress distribution in a dysplastic hip joint and a post-operative model. This study presents a virtual surgery scenario which contributes to the surgeon at the moment of planning and evaluating a surgery process. Estimating the biomechanical behavior of the pathological hip joint of a patient provides important information about the patient reality to define the more adequate surgery process to treat the pathology. In conclusion, this study presents a comparison of the stress distribution, in three scenarios, on a hip joint with residual dysplasia and on a model in which the articular components were relocated simulating a surgery process.

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