Stress Distribution Visualization on Pre- and Post-Operative Virtual Hip Joint

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1. Introduction

With the increase in computer power, more and more effort is being dedicated for building more realistic computational and graphical models to be used in clinical applications. This effort is important but is not sufficient in itself since clinicians need tools that can effectively help them in performing the regular tasks they are used to perform on biomedical images. Resulting biomedical datasets can be multi-dimensional and are usually very large, which makes them difficult to explore and understand [1]. Therefore there is a need for intuitive representations for end users to deal with this increasing complexity. At the same time, medical images do not describe functional aspects of the patient body that are interesting for diagnosis. For example, in Orthopedics, mechanical parameters like pressure on cartilages and tension on ligaments can be correlated to pain around a joint. To obtain that information, one possible solution is performing a biomechanical simulation of the joint.

In this paper, we present a case study using a spreadsheet-like interface for exploring biomedical datasets generated by a biomechanical model of the hip. The case we analyze here is an osteotomy corrective surgery that reorients the femoral body in relation to the femoral neck, somewhat like the intertrochanteric osteotomy described by Imhäuser [2]. That is a procedure recommended by most authors as a surgical treatment of severe slipped capital femoral epiphysis. Then we compare estimated contact area of the pre- and post-operative hips from a threshold of the computed stress.

2. Methods

Spreadsheet-like interfaces are a generalization of conventional spreadsheets where cells can contain graphical objects such as images, volumes, or animations or even widgets to interact with data. In this class of visualization systems, screen space is spent on operands rather than operators, which are usually more interesting to the end user [3]. They also benefit from the fundamental properties of spreadsheets where it is easy to organize, compare, analyze and perform operation on data. Our spreadsheet framework consists basically of: cells, operators and dependencies. **Cells** are the basic data elements. They can contain numbers, images, curves, vectors, matrices or widgets for interactive cells. The cells are organized in a tabular layout, which makes them easy to browse. **Operators** are applied to cells or ranges of cells and define the dependencies between the cells. A firing algorithm controls **dependencies** as in conventional spreadsheets and automatically updates the cells to reflect changes.

The data we use come from the biomechanical simulation of the human hip joint. Separated software [4], based on a conceptual joint model is used for hip simulation. The model is based on a hybrid approach. A kinematical component defines the bony rigid motion from measures on the static and dynamic MRI, while a biomechanical component computes soft connective tissues deformation, and allows estimating force exchange and consequent stress on those soft structures. Soft parts are discretized such that a generalized mass-spring system can process the deformations. Special considerations had to be taken into account to adapt traditional mass-spring system to medical applications. The most important is the correct biomechanical behavior of the biomaterials. In a previous work [5], we describe how we configure our springs lattice such that our virtual ligaments and cartilages have a predictable elasticity, defined by the Young's Modulus (E) of the material.

3. Results

A right hip model has then been built to illustrate a use case where the joint congruity is analyzed. The elements present in our hip are: the femur and the pelvis bones; the femoral head and the pelvis cup cartilages; the ischiofemoral ligament; the acetabular rim (labrum). The bones and the labrum are considered rigid, and the elasticity for the cartilages and ligament is defined to be 10 kPa. It is softer than the mean value found on the literature, but it allows our simulation to converge faster, while the stress distribution remains coherent. In addition, fibers orientation is taken into account for the ligament, in a way that it is anisotropic. The motion we performed is 90° of flexion plus total internal rotation, a key motion in Orthopedics.

To simulate the osteotomy operation, we deformed the 3D femur moving the distal extremity internally on the frontal plan, such that the hypothetic patient has to abduct his hip to keep the knee at its place. We represent this abduction as a reorientation of the femoral head – and consequently of the whole femur – such that the new anatomical axis of the femur keeps aligned with the original one. Then we applied the same motion on the osteotomized joint that we had applied on the original.

We could observe that the stress distribution on the cartilage surfaces, and consequently, the contact areas change.

4. Discussion

We present a case study combining our spreadsheet-like interface and our hip joint simulator to analyze the congruency of a 3D virtual hip before and after an osteotomy of Imhäuser.

The geometric data we used come from a healthy patient. Thus, it is normal that analyzing the results we obtained, one can see that the joint congruency was better before the operation. Anyway, the operation we performed has the goal of showing how we can assess the surgery at the planning phase and not actually improve congruency. We believe that with such tools for preliminary surgery planning clinicians to gain time and precision on diagnosis.

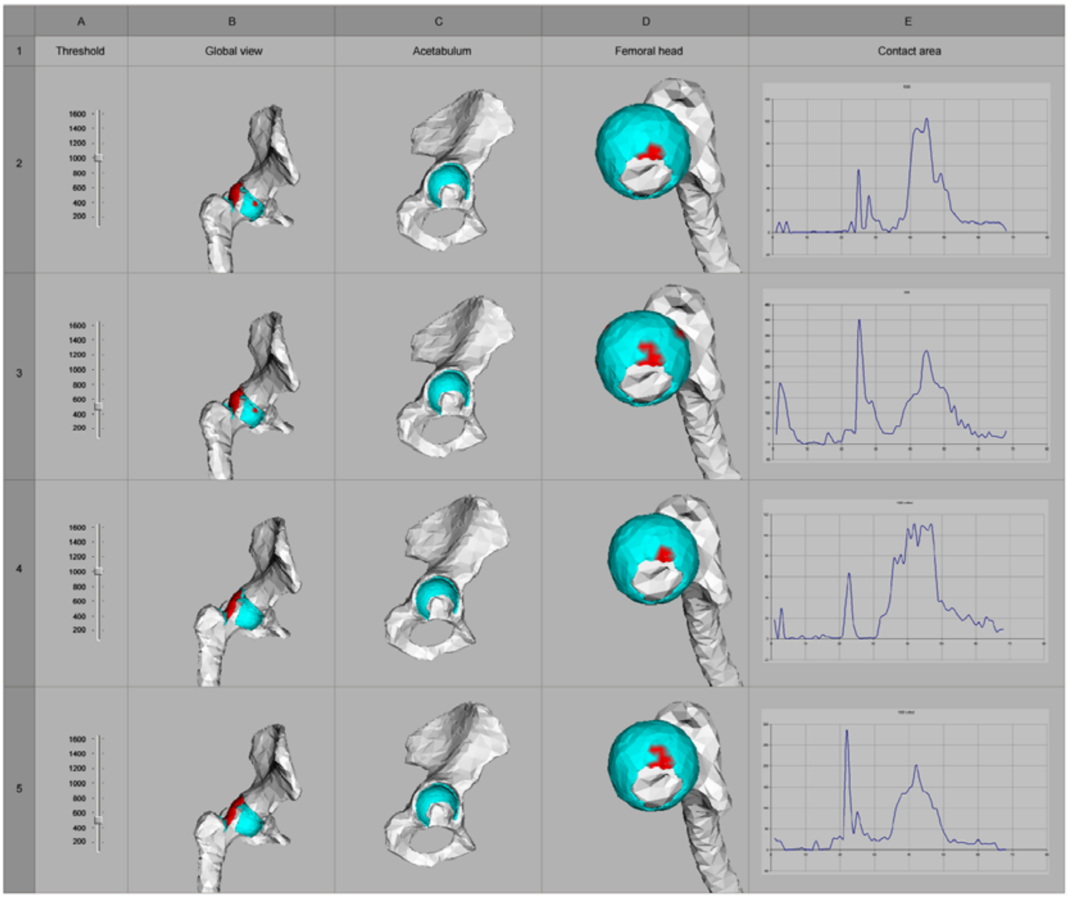

Figure 1 - A template comparing pre- and post-operative virtual hip. The contact area is estimated based on the stress calculated on the cartilage surfaces. A stress threshold was defined in A2 and used to determine the contact area on the animation in B2. Other views were derived (C2 and D2) and a graph of the contact area history is shown in E2. The row 2 was then copy-pasted into rows 3 to 5. Rows 2 and 4 represent simulated pre-operative situation for different threshold values. Rows 4 and 5 represent simulated post-operative situation.

5. References

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