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MODELING AND SIMULATION OF THE KNEE JOINT SURGERY

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Abstract— In this study, we will present the importance and the advantages of using simulation and modeling methods in computer-aided design to orthopedic surgical techniques. The 3D model of the bones was obtained using reverse engineering principles. The existence of the 3D model provides an opportunity to assess conceptually bone size, shape, specificity, structure, and the existing pathological situation. On the model we can consider references, elements such as points, lines and planes useful in surgery. It also can be made virtually the mechanical performed during actual operation such as drilling, bone cuts and the bone can be assembled with the implant used, achieving practically a virtual operation. The method will be exemplified in two common operations performed in the knee joint. Virtual operations will be carried out using the program CatiaV5R20. Great advantage is that obtaining better results allows a proper optimization of the virtual operation.

Keywords— ACL reconstruction, modeling, osteochondral transplantation, simulation, virtual operations.

I. Introduction

In medicine, notable progress has been achieved to bet when it started to use the modeling and simulation techniques in biomechanics, as research methods used for investigating the human body. Thus the body was regarded as a superposition of multiple systems, appliances, organs, functions, physical and functional well-defined, complex interconnected, after well-defined laws.

As it is known, the simulation is the process that allows the representation of the real process through an idealized model, which is realized physically or conceptually, and which allows us to obtain information regarding its behavior. This is very useful especially in cases, where the direct analysis is not possible, namely clench system can be made available for testing or when the analyst can not be generated directly from experimental conditions. The solutions obtained after simulation may not even be accurate, while the fact that models are imperfect, that there may be errors or clarifying in simulation data.

As a principle, the method is based on a graphic file containing the model obtained from the patient's bone from CT or MRI images [3]. It can be analyzed conceptually size, shape, particular structure, etc.. Then in the same file you can upload graphics and CAD files that will be used in operations such as dentures, implants, grafts, etc..

One can regard the reference-points, lines, planes useful for operation. Also virtual mechanical actions can be made, such as drilling, cutting bone cuts and brought in assembly, or implant prosthesis used practically for realizing the virtual operation.

Finally the quality of the operation can be verified using CAE methods, consisting of mesh components, placing constraints and forces that require bone surgery, mechanical to achieve tension and strain.

II. Modeling and Simulation of a Virtual Osteochondral Transplant Operations and LIA Reconstruction

Knee joint, the largest component of the human body is quite vulnerable, due the fact of the high static and dynamic applications that is subjected to [1]. The consequence of these applications is the appearance of aging and damages in the contact areas [2]. Therefore, we believe it is of interest to study the development of simulations of two frequent operations, namely: mosaicplasty by osteochondral autologous transplantation and anterior cruciate ligament reconstruction.

The steps to be taken in such a virtual simulation are:

1) analysis of 3D bone model in terms of geometry, conditions, features pathological situation;
2) insertion of control and reference geometric elements that we need for the intervention;
3) modeling elements needed: grafts, implants, transplants, fasteners;
4) achieving effective action in the job relative to reference elements such as drilling, cuttings, grafts sampling, etc.
5) importing CAD graphic files that are necessary (implants, transplants, etc.)
6) making effective surgery by assembling the bone with the other elements.
7) checking the operation in normal operating conditions.

A. Mosaic Plasty through Osteochondral Transplantation

Mosaic plasty is an action that is performed when the knee arthrosis results from wear of the cartilage in the contact area.

Osteochondral transplantation is a bone transplant in the femoral condyle of the knee. The transplant involves inserting osteochondral cylinders with a length of 20 mm and a diameter of 8 mm or 6 mm. Cylinders were collected from the lateral and also from medial if needed, and the femoral trochlea and the femoral condyle was transplanted in the internal load area [4].

Femur model used for modeling was done by computed tomography (Fig. 1)

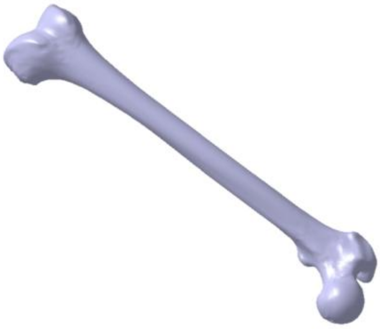

Fig. 1. Femur model obtained by CT

In the first step we will analyze the 3D bone model in terms of geometry, conditions, features pathological situation.

The first step, modeling procedure, consists in creating plans [8] in the femoral trohlei tangent of which is harvested the osteochondral cylinder.

In this plan were created points that were later transformed by command Hole in bores (Fig. 2).

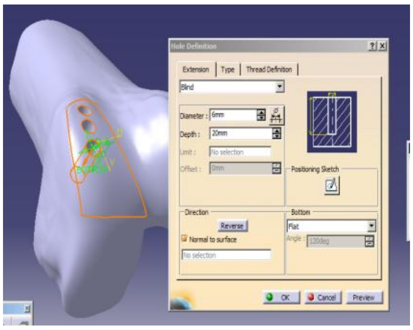

Fig. 2. Bores creating

It will be yield by nine osteochondral cylinders. The obtained result is illustrated in Fig. 3.

Fig. 3. Femur after harvesting osteochondral cylinders

For arthritis affected area, the first step we need is a calculation on the number of cylinders that can be entered into it. We create the necessary bores in the same area.

The virtual surgery will be done, by assembling the drilled bone with the osteochondral cylinders.

Osteochondral cylinders are modeled and assembled (Fig. 4.).

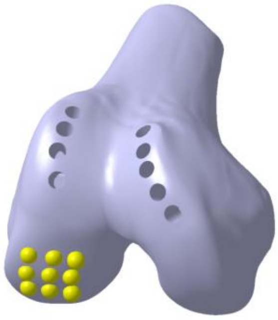

Fig. 4. Model obtained after osteochondral cylinder assembly

The ensemble will be used to determine the status of CAE, in order to study the stress and the strain [7].

We applied a force along the mechanical axis of the assembly, considering as a fixed constraint at the level section by tibial shaft. The force applied was 1200 N, in order to maintain a safety margin with regard to the stability of the graft used for further analysis, the value corresponding to 120 kg support man unipodal.

The simulations were made in Ansys [TRF] enabled 1,200 N load analysis of multiple parameters at any point in the femur bone and transplanted osteochondral cylinder. The following were evaluated: strain equivalent total shift, main voltage, Sigma von Mises equivalent stress and safety factor.

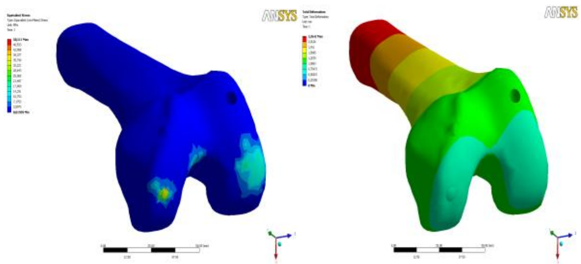

Fig. 5. The maximum displacement obtained from the distal femur

Maximum equivalent strain of the femur bone was obtained from the transplanted osteochondral cylinder surface: 0.0026941 mm / mm. The maximum displacement obtained from the distal femur was 2.2642 mm, obtained from the minimum to the femoral shaft and articular surface of the femoral condyles (Fig. 5).

Principal stress was also obtained at the surface of the transplant and has a value of 44 021 MPa. Von Mises equivalent stress sigma, with a total of 50 111 Mpa, was obtained throughout the whole femoral condyle (Fig. 5).

Safety factor, which is the ratio of allowable stress in compression and tension analyzed bone segment specific bone equivalent (von Mises sigma), is at the minimum level of 2.5943 osteochondral transplantation.

B. LIA Reconstruction

ACL reconstruction is made in order to replace the torn ligament with a new structure (tendon), prepared by reshaping an auto or allograft surgery.

While arthroscopic techniques have spread increasingly with the development of technology and skills of surgeons, an arthroscopic reconstruction was required.

The modern ligamentoplasty LIA is performed arthroscopically and follows several distinct phases: selection and graft harvesting, preparation space receiver, tunnel drilling, placing and fixing the graft and postoperative functional recovery. The aim is to regain normal joint stability and mobility to restrict arthritic changes and winning on the medium and long term comfort [5].

An interesting aspect is the fixation of the graft in the tibial tunnel. In Fig. 6 it is a simple attachment semianatomic, intraosseous.

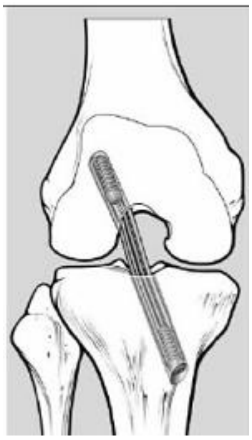

Fig. 6. LIA reconstruction [6]

Since femoral fixation is, on the one hand made through the safest position, on the other hand it results that PROV fixing tibia and femur can be extrapolated. In conclusion it will shape model tibia ACL reconstruction.

In the first step we will analyze the 3D bone model in terms of geometry, conditions, features pathological situation.

Tibia model that is used for modeling was available after computed tomography. Modeling steps coincide with stages operators.

The next step will consist in creating the modeling elements that we need: drilling the tibial tunnel, modeling the resorbable screw and modeling the graft.

For drilling the tibial tunnel, is considered a frontal plane tangent to the tibial tuberosity. On this plane is considered a vertical line about 1 cm from the tuberosity. Then, we will insert a point in the LIA area. From that point, a straight line is drawn to intersect the right vertical desired angle (45,55,65 degrees) for osteotomy. The line follows the second point that we need for creating the tibial tunnel axis.

Perpendicular to this axis we need to build a plan that will be needed for performing a 2D sketch tibial tunnel. (Fig. 7).

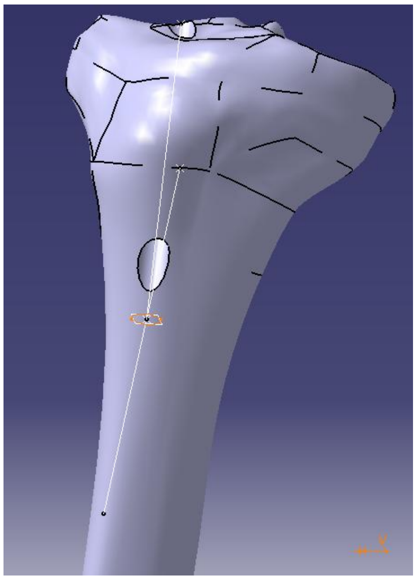

Fig. 7. Tibial tunnel drilling

The tunnel will be created using Hole command. Resorbable screw (Fig. 9) was modeled taking into account the shape, using the Shaft command. For the graft modeling (Fig. 8), were taken into account the facts that during the installation, a pressing between the screw and the tibial wall practically takes place. Therefore, for the modeling at one end, it was modeled as negative, the resorbable screw.

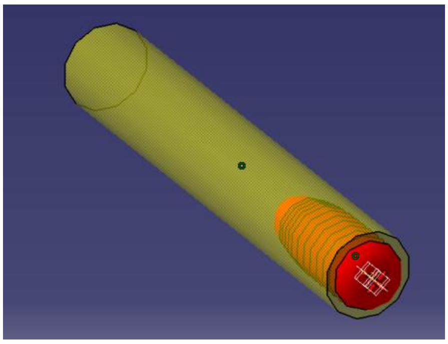

Fig. 8. Resorbable screw and graft

The last step will be the assembly simulation, achieving their ACL reconstruction by simple fixing semianatomic, intraosseous.

Although this not exactly the sequence assemblies from the actual operation, it was initially assembled the screw and the graft. For the other two items, those were subjected to the constraints of coaxiality and Offset screw 2 mm outside the graft.

Then this subset, tibial tunnel was fitted using the same set of constraints that coaxiality bore axis between the first subassembly made in the tibia, respectively Offset constraint (Fig. 10).

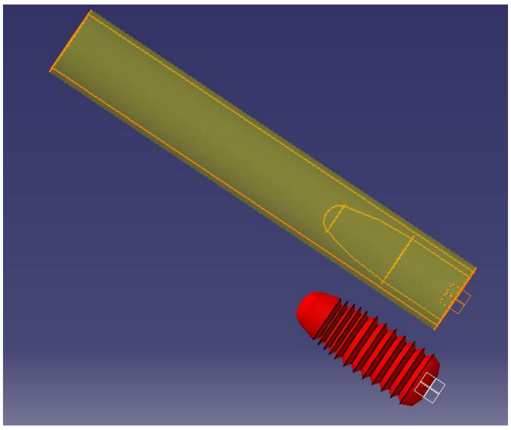

Fig. 9. Resorbable screw and graft

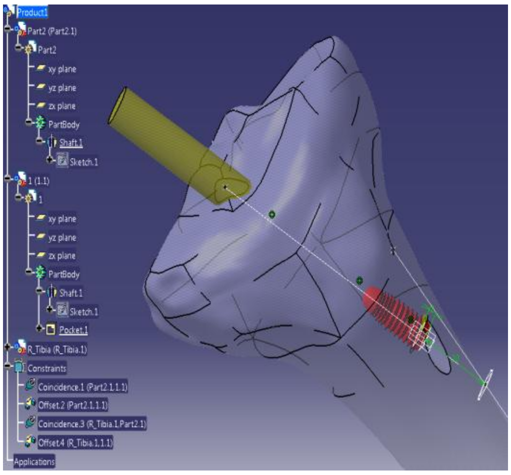

Fig. 10. The resulting assembly

III. CONCLUSION

This study demonstrates the importance and advantage of using simulation and modeling in the case of orthopedic surgical techniques.

Creating such models is very convenient and effective for orthopedic surgical techniques, as in the case of obtaining better results, than virtual operation can be resumed properly optimized.

These modeling and simulation has many advantages:

1) the possibility of virtual simulation of the operation has at least two advantages: the possibility of learning and practicing techniques in a virtual environment and using the typical particularities of each patient.
2) study of stress and strain states of the system created by CAE methods;
3) study of the fixing systems;
4) optimized form elements such as resorbable screw, graft, etc..

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