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PHD THESIS ABSTRACT

ANALYSIS OF THE MECHANICAL STABILITY OF THE IMPLANTS USED IN THE RECONSTRUCTION OF ACETABULAR BONE DEFECTS AFTER TOTAL HIP ARTHROPLASTY

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CONTENTS

Keywords: hip prosthesis revision, virtual model, hip joint, orthopedic implant, finite element analysis, mechanical behavior, parameterized virtual environment

Analysis of the mechanical stability of the implants used in the reconstruction of acetabular bone defects after total hip arthroplasty

Abstract

The hip joint, from a mechanical point of view, is of the spheroidal type that allows rotations on the three axes of movement, having an important role in the statics and locomotion of the human body.

The pathology of the hip that requires a prosthesis shows a change in joint morphology. Among the most common diseases in medical practice that have as final therapeutic solution hip arthroplasty are primary and secondary hip osteoarthritis, followed by traumatic diseases, femoral fracture and pseudarthrosis of the femoral neck, the final stage of aseptic femoral head necrosis, and rheumatoid arthritis spondylitis.

The treatment of hip pathology has evolved in the last two centuries, from rudimentary surgical procedures to modern hip arthroplasty, with a marked explosion in the last 30 years, considered one of the most successful operations to date. Hip arthroplasty is a permanent challenge due to the desire to discover the "supreme prosthesis", for which the competition is still open.

Endoprosthetic arthroplasty can be defined as reconstructive surgery with bone slaughter and prosthetic replacement of joint components.

Particular aspects, however, appear during the revision of the hip prosthesis. In addition to the dislocation of the prosthesis, there are bone regressions in the acetabular area, increased contact area of the prosthesis cup, bone absences, cracks of the pelvic bone. For this reason, surgery to restore the hip joint in these special situations is subject to additional challenges. Also, these interventions are usually performed in elderly patients and special techniques are used to restore the additional metal elements of the prosthesis.

There are several methods of prosthesis and obviously several surgical revision techniques. The main interest of this study was to identify that method of revision of the hip prosthesis that retains as much bone material and has similar mechanical strength.

Analyzing the techniques, methods and models obtained in this doctoral thesis, the following observations were highlighted:

• The components of prostheses and revision systems are parameterized, so that they can be adapted to various anthropological dimensions;

• By attaching these revision systems to virtual bone components, various "in vitro" analysis can be obtained.

• These models can be used in various tests or real or virtual experiments;

The studies presented in this doctoral thesis had, in general, three directions:

- a clinical and statistical study performed on a group of 23 patients;
- an experimental study consisting of four revision orthopedic assemblies and testing their mechanical strength;
- a virtual-experimental study that analyzed the behavior of the four revision assemblies and the non-prosthetic joint, when the loads are similar to normal gait, using the finite element method. Innovative techniques were used in these simulations and analyzes, through which the geometry of the bone components was obtained from tomographic images taken from real patients.

By studying and analyzing the values of the forces to which the four orthopedic revision assemblies yielded, the following conclusions and observations can be drawn:

- the standard reference assembly was the most resistant, yielding to a force value of 1850 Kgf, ie 18148 N;
- the assembly with structural graft was the least resistant, and the force to which it yielded was 1680 Kgf, ie 16480 N;
- the assembly with fragmented graft and reconstruction net yielded to the force of 1790 Kgf, ie 17560 N, values very close to the maximum value of the force;

- studying the values of the forces obtained at the failure of the four assemblies, it was found that between the lowest value of the force and the highest is only 170 Kgf. This finding allows us to conclude that all four assemblies provide a sufficiently good strength.

Analyzing the maximum values obtained in the five simulations using the finite element method, the following conclusions can be drawn:

- the highest values of displacements were obtained in the case of the integral hip joint, and the lowest were observed at the standard reference assembly;
- the maximum deformations were obtained at the integral hip joint, and the smallest in the case of the standard reference assembly;
- the highest stresses were observed when mounting with a structural graft, and the lowest in the case of the integral hip joint;
- High values of strains and displacements indicate that the integral hip joint is more elastic than the prosthetic hip;
- Analyzing the more stressed areas and surfaces from the four overhaul assemblies, the maximum stresses are found on the prosthesis elements, and the bone components that are in contact with them are less stressed;
- If we study the comparative diagrams of breaking forces and stresses in the four orthopedic revision assemblies, we find that the assembly with structural graft is the most tense and, consequently, yielded to the lowest force, which validates the two studies (virtual and experimental).

The following general conclusions were also highlighted:

- using CAD and FEM methods, very complicated biological systems can be modeled and simulated;
- the virtual models proposed in this paper have been experimentally validated;
- finite element analysis methods, coupled with virtual reconstruction of CT or MRI images and reverse engineering methods, pave the way for the innovation of customized orthopedic systems for each patient.

In Chapter 1, entitled "Elements of descriptive anatomy of the hip joint" was presented, in general, the anatomy of this important joint of the human locomotor system. The upper epiphysis of the femur, the articular capsule, the pericapsular ligaments, the round ligament of the femoral head have been described. Also, the muscular apparatus of the hip, the innervation of the hip and the vascular system were detailed.

Chapter 2, entitled "Planning for Primary Hip Arthroplasty," first described the patient's preoperative evaluation and preparation and imaging evaluation. Next, the technique of implanting a primary prosthesis was detailed with the approaches in hip arthroplasty, then the types of arthroplasty.

In Chapter 3, called "Loosening of the total hip prosthesis. Particle disease. Inflammatory granuloma", at the beginning, the term Loosening was defined, sometimes called loss or decimation. Subsequently, the particle disease, its staging and various histological aspects were detailed. Inflammatory granuloma has also been described.

In Chapter 4, entitled "Classification of acetabular bone defects. Solutions to repair them", for a start, the causes of bone deficit consisting of primary intervention, implant migration and osteolysis induced by particle disease were highlighted. Then, the AAOS and Paprosky classifications were detailed and the objectives of the acetabular revision were explained, ie, restoring the local anatomy so as to obtain a primary stability, restoring the center of rotation of the hip and ensuring a symmetrical gait. Finally, the technical solutions for joint restoration were detailed, depending on the acetabular defects.

In Chapter 5, entitled "Clinical and statistical research in hip prosthesis revision", a group of 23 patients hospitalized and operated in the Orthopedic Clinic of the Craiova County Emergency Clinical Hospital in an interval of 8 years (2007-2011) was analyzed and studied.). Using the methods of medical statistics, different prevalence criteria were studied and analyzed, such as: age and sex, type of bone defect according to Paprosky classification, bone repair solutions, amount of blood lost during surgery, number of hospital days, comorbidities patients, but also other criteria that were considered important.

In Chapter 6, entitled "Performing orthopedic hip revision assemblies" were recreated, using bone components taken from the animal and real prosthetic elements and using specific instruments, four assemblies used for hip revision such as:

- overhaul assembly with titanium augmentation;
- standard reference overhaul assembly;
- revision assembly with structural graft;
- overhaul assembly with fragmented graft and reconstruction net.

Chapter 7, entitled "Experimental Testing of Orthopedic Hip Revision Assemblies", first described the devices and methods applied for testing. Also, a fixing device for these assemblies was designed and modeled, which was practically made. Using this device through which the orthopedic assemblies were fixed on a universal test machine, the forces to which these orthopedic systems failed mechanically yielded were obtained. The data were organized and analyzed.

Chapter 8, entitled "The Virtual Model of the Integral Hip Joint," first describes the hardware and software tools used. Also, the main methods by which virtual bone components can be obtained starting from tomographic images have been identified. Innovative techniques and methods were used, through which, starting from the gray shades of the different tissues from the tomographies, the primary geometries of the bone components were obtained for the beginning. Through various software techniques, these primary geometries have been transformed into virtual solids. Finally, the virtual bone components composed of virtual solids were assembled and the virtual model of the human integral hip joint was obtained.

In Chapter 9, entitled "Virtual Experimental Testing of Orthopedic Hip Fits for Normal Walking", we first set out the techniques and methods used to obtain the mechanical behavior of the four orthopedic assemblies, but also for the hip. human integrity. These virtual models, taken from a CAD environment, were imported into a finite element analysis program. In this program, the necessary materials and their physical-mechanical properties were first established. Then, the models were divided into finite elements of tetrahedral shape, the imposed constraints and loads specific to ordinary human gait were established. Finally, for the five situations, the applications were run and result maps were obtained.

In Chapter 10, entitled "Discussions, conclusions and original contributions", several important aspects were exposed that emerged from the studies presented in this paper, highlighting the original elements of the thesis.

The analysis of the content of the chapters of this doctoral thesis highlights, at least, the following original elements:

- study, analysis and practical realization of orthopedic hip revision assemblies using animal bone elements;
- the design, modeling and practical realization of an original device that allows the fixing and orientation of the revision assemblies for experimental testing;
- the use, originally, of experimental devices and techniques used in engineering to obtain experimental data for overhaul assemblies;
- the use of engineering-specific methods and techniques, originally, to obtain three-dimensional models of the revised assemblies studied and analyzed;
- the coupling, in an original way, of medical imaging techniques with methods of reconstruction and three-dimensional modeling;
- the use of high-performance equipment and programs for three-dimensional modeling and finite element analysis of overhaul orthopedic fixtures;
- coupling the experimental methods with the virtual-experimental ones for mutual validation;

- the vast majority of figures, images, tables, graphs, diagrams, result sheets are original;
- acquisition, storage, integration, interpretation, in an original way of virtual-experimental data.

From the analysis of the orthopedic systems for revision of the hip prosthesis, it was found that the orthopedic installation with a fragmented bone graft and reconstruction net ensures both a good primary resistance and a durability of the assembly. It also ensures the reconstruction of the acetabural cavity and the full integration of the graft by restoring the local anatomy, the integrated bone tissue being viable and thus able to withstand daily demands. These conclusions were validated, both by experimental testing and by the finite element analysis method, using the load specific to normal human gait.

This doctoral thesis tries to bring to the fore the complicated pathological situations that occur due to the failure of hip prostheses and their replacement with overhaul prosthesis elements. Also, different variants and solutions were analyzed to ensure a rapid recovery of the patient, with minimal bone sacrifice. The installation with a fragmented graft and reconstruction net was highlighted, which has all the elements to become a remarkable solution.