EXPERIMENTS AND SURFACES CHARACTERIZATION OF THE FEMORAL HEADS OF HIP PROSTHESES

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Total hip prostheses are necessary when the human hip joints are disturbed due to illness, under the negative influence of factors determined by the mode of human life or due to different accidents. Hip prostheses durability is influenced by the materials used to be made. Taking into account that is still complicated to increase hip prostheses durability, we started to characterize these prostheses in order to continue with nanomaterials coatings.

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1. Introduction

Human body's motor apparatus is composed of elements which allow mechanical interactions between human body parts and environment.

The joints are included in the interstitial elements system and are designed for transmitting fundamental components of the whole motor system's movement. Joint is a system with passive components (such as articular ends of bones, cartilages, ligaments, synovial fluid) and active components (muscles). Kinematic parameters of the joint (e.g. the number of degrees of freedom) follow the shape of the bone surfaces in contact. The joint is a moving structure, but the ligaments are intended to limit mechanically the potential movement, to steer the surfaces in contact and to stiffen the joint. Depending on the shape of the contact surfaces that determine the potential of joint motion, there are:

- ball joints – which have spherical contact surfaces
- cylindrical joints - contact area has cylindrical surface
- ellipsoidal joints - contact surfaces are ellipsoidal
- planar (sliding) - contact surfaces are parallel with a plan
- amphiarthrosis - contact surfaces are irregular and have minimum capacity of movement
- combined - an anatomically autonomous joint is functional correlated with another joint and the movement in both occurs simultaneously.

The hip is essentially a ball and socket joint, formed by the articulation of the rounded head of the femur and the cup-like acetabulum of the pelvis. It forms the primary connection between the bones of the lower limb and the axial skeleton of the trunk and pelvis. The cup-like acetabulum forms at union of three pelvic bones and the joint may not be fully ossified under the age of 25 years. The large head of the femur attaches directly to the acetabulum. The head of the femur is attached to the shaft by a thin neck region that is often prone to fracture in the elderly, mainly due to the degenerative effects of osteoporosis.

Hip joint's biomechanics. Due to the spherical shape, the joint has an inherent stability by its design. This does not alter the remarkable mobility of hip joint. In the joint, large forces are generated by the strong periarticular muscles, which balance the body's weight amplified by the

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bone levers. Any flaw in the joint mechanism changes the intra-articular forces distribution, causing degenerative changes.

Hip joint's kinematics examines hip movements geometry apart from the force qualities it generates. Depending on the periarticular muscles, joint movements are performed in three planes of space and can be reduced to three pairs of fundamental movements performed around the three main axes of the joint. They intersect at the joint center of rotation, which corresponds to the center of the femoral head. These axes allow:

I. free extremity movements from the pelvis considered the fixed point;
II. movements of the pelvis to the free extremity fixed to the ground.

Considering the fixed point in the pelvis, the following possibilities can be distinguished for the movement of lower limb extremity from neutral-zero position (the human body anatomical position): flexion and extension movement (on or from the spine and on or from the thigh), abduction and adduction of the femur, internal (medial) and external (lateral) rotation of the pelvis, thigh or spine (Fig. 1).

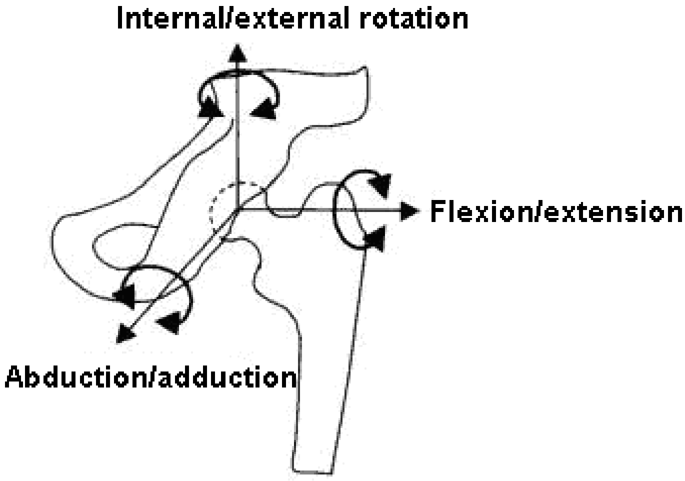

Fig. 1. Movements in the hip joint.

Flexion and extension movement is performed to a transverse axis disposed in the frontal plane. The forward motion of the lower limb towards this axis achieves flexion (anteversion) and back movement achieves extension (retroversion). These two movements are the most important to the hip joint. Flexion's amplitude is dependent upon the position of joint in the frontal plane (abduction and adduction). For example, the maximum flexion is achieved during easy abduction and neutral rotation positions. Passive movement is performed with highest amplitude and is limited by the contact between the soft parts. During normal movements of the hip joint are performed rarely pure movements after a single axis. Most times they are in the form of combinations of the three main types of movements.

Normal function of joints may be disturbed due to illness and under the negative influence of other factors determined by the mode of human life and professional activity. Osteoarthrosis is one of the most common forms of arthritis and is accompanied by gradual degradation of cartilaginous tissue. In such cases there is mutual friction of the bones, causing pain and accordingly result in partial or complete loss of joint mobility. Osteoarthritis is a disease in which the cartilages that lines and protects the joint surfaces deteriorate with the passage of time. This damage occurs as a result of chemical changes in the cartilage. Excessive body weight tensions joints, especially those that support weight, such as knees, hips and joints of the talus. Osteonecrosis is a disease of bones, which occurs as a result of reducing or stopping blood irrigation of a certain portion of the bone. The disease causes the appearance of small cracks and defects in bones, which evolves over time and lead to bone destruction. Fractures of the femoral head may lead to un-consolidation and osteonecrosis, the appearance of decubitus caused by long horizontal position of the patient, ultimately causes death. Accidents produced by the simplest ways can have blasting results. In the final stages most joint diseases cause disability and pain sensations become very pronounced.

In such cases the drug treatment does not give positive results, so the only way to alleviate pain, to restore limb length and joints mobility is pseudo-joints implantation. Arthroplasty surgery consists in the regeneration of the joints fragments damaged by disease using pseudo-implants.
A total hip prosthesis (THP) consists of three parts (Fig. 2):

- a cup that replaces the hip socket;
- a ball that will replace the fractured head of the femur;
- a stem that is attached to the shaft of the bone to add stability to the prostheses.

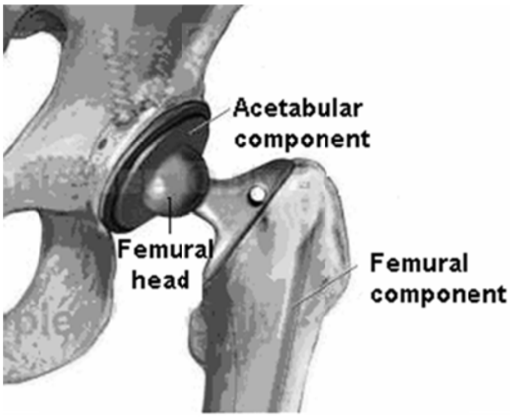

Fig. 2. Components of a total hip prosthesis.

Joint component of femoral prosthesis is a piece of metal sphere made from different alloys or ceramic (aluminum oxide or zirconium oxide). Prosthetic head and polyethylene acetabular cup with much larger diameter and thicker wall lead to the formation of a friction torque increased by the radius difference of components. Cup having large outdoor diameter decreases the pressure per unit area, reducing the chances of bone resorption and loosening chances.

Joint element influences the wear speed of the cup by the metal surface finish (which determines the coefficient of friction), by the angle of movement achieved in each cycle (determined by head's diameter) and by the type of lubrication that allows it.

The articular surfaces mainly deteriorate due to the high superficial pressures produced by mechanical movements of the body.

The deterioration process has a complex mechanism, combining abrasive wear, adhesive wear, third body wear and fatigue wear [1] (Fig. 1).

Abrasive wear [2] represents the removal of material from one surface by the other.

Adhesive wear is produced where localized bonding of the two surfaces occurs, such that the attachment force is stronger than the yield strength of the material. A small piece of material is removed from one surface and is attached to the other.

Third body wear refers to the insertion of a wear particle between two moving surfaces [3].

Fatigue wear can lead to subsurface cracks propagating and flaking off of particles from the surface. High subsurface stresses can also be caused by third bodies between the two articulating surfaces leading to accelerated fatigue wear.

2. New materials for hip prostheses surfaces improvement

So far it has not succeeded completely removing the problems associated with the use of hip prostheses: loosening and fracture, rejection physiological reactions of the body and the most important, material wear. Therefore, it is necessary to have a resistant prosthesis, with anticorrosive composition and high mechanical properties.

Stainless steel, titanium alloy, polymers and ceramic composites undergo degradation after 10–15 years of use. Due to this reason, materials engineers must consider the physiologic loads placed on the implants. Material choices also must take into account immune system biocompatibility, the environment, corrosion issues, friction and wear of the articulating surfaces.

Sliding surfaces must be usually hard to keep the wear to minimum values. Ceramics, which have a very high strength, are not resistant to tearing and have a marked fragility. Metallic materials are relatively soft, but resistant to breakage. Thus, it is difficult to counteract adhesive and abrasive usages using the same material. Metallic biomaterials have different influences on the human body, is distinguishing different forms of biological reactions, according to: concentration of metal, exposure time and route of administration.

Generally, pure metals are rarely toxic. Toxic and allergenic effects depend on the concentration and nature mixtures (oxides, simple or complex salts). Two compounds of the same metal can induce strong responses, but different.

Cobalt-chrome alloy femoral heads articulating with UHMWPE acetabular liners have been the main stay of hip arthroplasty for more than 30 years. Zirconium alloy substrate is relatively soft when compared with cobalt-chrome alloy femoral heads and may deform in contact with acetabular shell materials in the case of dislocation. In the case of ceramics, with extremely low wear rates, remains a risk of catastrophic failure because of the inherently low fracture toughness of the materials. Oxinium components have a unique ceramic layer (4 μm thick) to mitigate the wear, akin to a zirconia ceramic material, and have an integral metal substrate that provides toughness and high fatigue strength.

Materials used for coatings.

International scientific community has made and still makes efforts to increase hip prostheses durability. In order to improve mechanical properties of hip prostheses, these have been coated with different materials, which have superior properties.

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Metal–matrix composite (MMC) coatings reinforced with hard ceramic particles are promising materials for improvement in various mechanical properties over conventional monolithic alloys.

A thin hydroxyapatite (HA) coating applied on textured metal surfaces [4], combines the mechanical attributes of metals with osteoconductive properties of metals and with the biocompatibility of ceramics [5].

Raw nanomaterials – which include nanoparticles and nanocrystalline materials that are readily manufactured and can substitute less performant bulk materials - can be also used as coatings in bone replacements, prostheses, and implants.

3. Experimental device

We studied the femoral heads surfaces of hip prostheses in order to see the level of wear.

Wear processes occurring inside different prostheses are an important source of debris, but these changes are often impossible to see with the naked eye. A methodology of ascending degrees of resolution was established using macroscopic, microscopic and nanoscale measurements. For these reasons we are trying to characterize femoral heads surfaces using a complex technique based on microscopic equipment [6].

We began with theoretical studies on sphere/plane thimbles, which simulated the femoral head and acetabular cup (Fig. 3). In the present case, the plane is the acetabular cup pressed by the spherical head, which destroys, in time, the prostheses [7]. Using this device and considering a vertical and static charge, we study the tribological properties of hip prostheses; determine the wear factor, the volume of material and the medium depth of the layer removed by wear process.

We realize hip prosthesis topography of these parts by using an atomic force microscope (NTEGRA Probe Microscope) working in the noncontact mode. Working principle of AFM is to measure the interaction force between tip and sample surface using special measuring heads, made of a cantilever with a pointed end. AFM images were processed using Nova SPM software. In this way was obtained the roughness of the studied surface and had been calculated other tribological parameters.

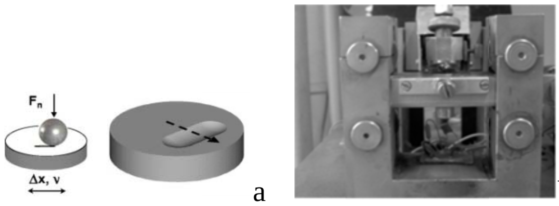

Fig. 3. Coated disks were tested articulating against a ball (polished surface) on top of a disk (a) and experimental device (b).

4. Results

Some results obtained after our experiments are presented in Fig. 4.

The optical microscopy study of a femoral head, made before coating, revealed that a high percent of the entire surface has isolated micro-scratches despite of polished macroscopic aspect. It was identified an embedded wear particle which scratched the femoral head surface (Fig. 4a, 4b). The large scratch could be related to the abrasion due to third body, namely the wear particles. Signs of severe micro-cutting were detected also in another region (Fig. 4c). In Fig. 4d one could observe small scratches and pits produced by biotribological corrosion. The corrosion pits occurred due to strong mechanical loading combined with the local temperature increase, at the contact interface.

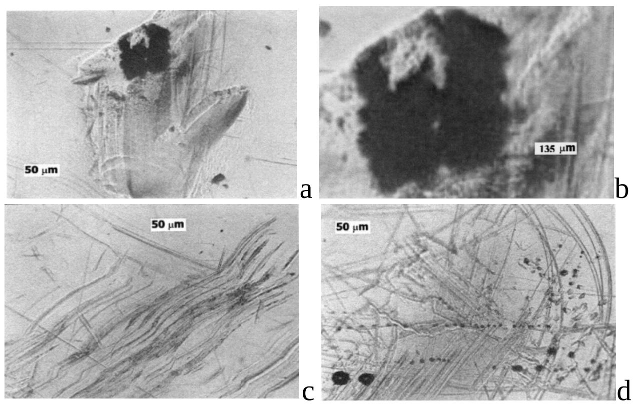

Fig. 4. Images obtained with AFM. Scratching (a), embedded wear particle (b) micro-cutting (c) and corrosion fretting (d) of femoral head.

Similar results were also obtained for the others parts of the femoral head. Three special areas were observed on the femoral head made from Ti. There are regions with a polished visual aspect and areas with a small level of luminosity. In the second part appears a high deterioration degree, with a lot of scratches. The third category of regions covers more than 50% of the femoral head and has an intermediate level of luminosity. Here, the deterioration level is not so high.

Using AFM measurements it can be determined exactly the surface's roughness and can be observed all the surface bumps (Fig. 5, Fig. 6, Fig. 7). As it is shown in the following examples, the roughness has different values (in different parts of the same femoral head), depending on the movements of the body that uses the prostheses.

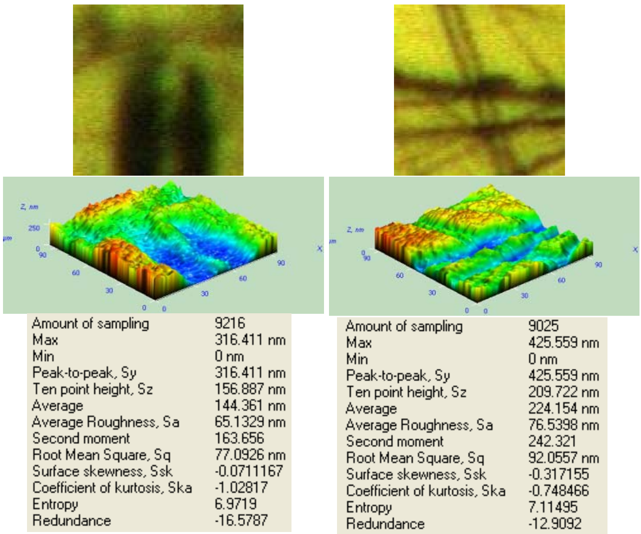

Fig. 5. Stainless steel surface microgeometry and tribological parameters measured using NTEGRA Atomic Force Microscopy

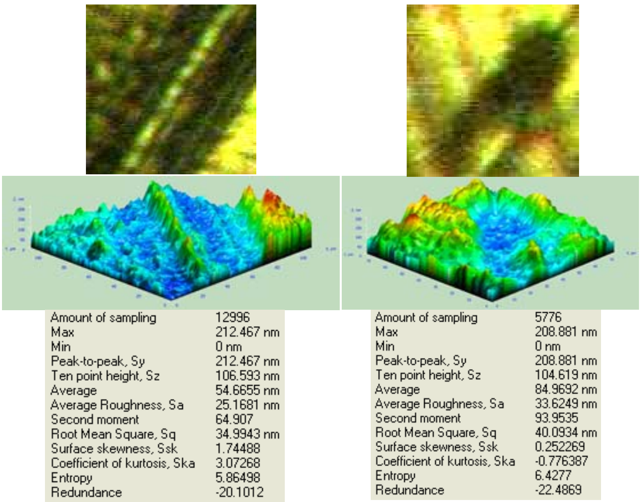

Fig. 6. Ti6Al4V surface microgeometry and tribological parameters measured using NTEGRA Atomic Force Microscopy

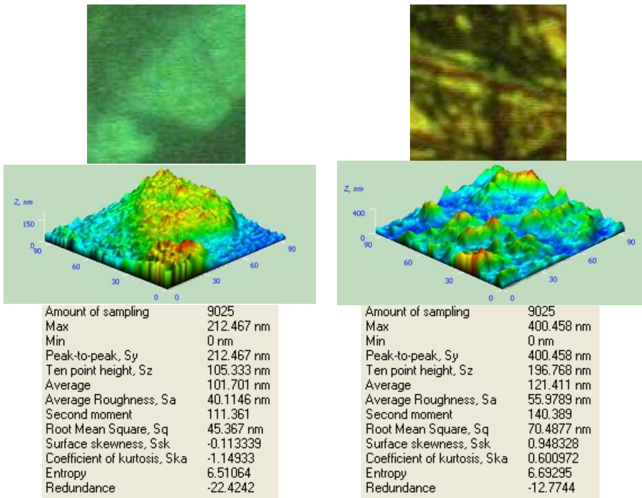

Fig. 7. CoCr surface microgeometry and tribological parameters measured using NTEGRA Atomic Force Microscopy.

After few experimental results it was observed that the friction is highest in tests with stainless steel and slightly lower for Ti6Al4V. Taking into account these measurements, the femoral heads surfaces will be coated in order to observe the favourable coating material.

5. Conclusions

As it was demonstrated in the last years, femoral head damage may occur during hip joint movements and may lead to accelerated materials wear. In order to obtain a clear characterization of the femoral head surfaces the study of its topography is useful. Such a study can be made by different techniques, but we decided on AFM because its images display high quality and dense nanocrystalline structure of prepared thin films.

Taking into account the obtained results we shall continue the research and AFM microscopy studies. The next steps will be based on femoral heads surfaces coatings that offer the opportunity to improve system's properties. Different materials will be used and characterized to protect against hip prosthesis breakdown.

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