LUBRICATION MODEL OF A KNEE PROSTHESIS, WITH NON NEWTONIAN FLUID AND POROUS ROUGH MATERIAL

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***Abstract*— Tibial component of knee prostheses, made of ultra high molecular weight polyethylene (UHMWPE), experiences a high degree of wear and may be expected to last twelve years on average. In this work, a steady state one-dimensional lubrication model of a knee prosthesis is solved through a numerical technique based on the Finite Element Method. The model takes into account a non Newtonian synovial fluid, its ultra filtration mechanism and the surface roughness of a porous elastic layer on the tibial component. The benefits of a porous compliant material placed at the top of the metallic tibial component are shown taking into account the stiffness and exudation capacity of the material and hyaluronic acid concentration of synovial fluid.**

***Keywords*— knee prosthesis, non-Newtonian fluid, elastohydrodynamic lubrication, wear, finite elements method.**

I. INTRODUCTION

Ultra high molecular weight polyethylene (UHMWPE) wear debris are currently the major cause of aseptic loosening of knee prostheses (Williams, 2003). These wear particles remain within the synovial fluid surrounding the implant and stimulating ostheolysis at the bone-implant interface. By this fact, the prosthesis is loosened and may be expected to last on average twelve years.

The interest in giving a solution to failures of knee prostheses is linked to the increasing demand of these implants by patients under 40. Young patients are generally active people, who might require several revisions (new replacements) during their lives. Therefore, the development of new materials and the improvement of the current polyethylene mechanical response are required in order to produce more durable prostheses.

Previous theoretical works showed that the optimization of the joint lubrication mechanism is a fundamental issue in improving the mechanical performance of the healthy knee. Both the low rigidity and porosity of the natural cartilage make the knee a well lubricated joint when it is working under high loading conditions. The self-lubrication mechanism promoted by the cartilage porosity has been shown to be one of the main reasons in producing very low friction (Corvalán *et al.*, 1999; Di Paolo *et al.*, 1998). By this mechanism, the surfaces in contact of the joint appear to be separated by a lubricant film for any loading condition, avoiding direct contact.

In the past few years, much interest has been directed toward the application of the elastohydrodynamic theory to artificial joints design. The minimum film thickness was predicted by Jin *et al.* (2003), based on the analysis of an artificial hip joint consisting of a metal femoral ball articulating against UHMWPE cups. Various comparisons of the predicted minimum film thickness were made between different bearing surfaces, elastic models, loading conditions and steady-state and transient conditions. They concluded that the minimum film thickness under cyclic conditions can be accurately estimated by a steady-state model using the column model for the computation of the elastic UHMWPE deformation.

The elastohydrodynamic lubrication theory applied to linear contacts was used by Di Paolo and Berli (2006) for a model of a metal-on-compliant layer knee prosthesis. The model considers the non-Newtonian (pseudoplastic) characteristic of the synovial fluid and the capacity to exude and absorb fluid by the compliant layer. It was shown that the pseudoplastic characteristic of the fluid benefits the lubrication mechanism by reducing the fluid viscosity when the film is narrowing. Consequently, the shear stresses at the compliant surface are reduced. In the same work, it was predicted that a material with the stiffness of the UHMWPE generates thinner fluid films than the surface roughness, thus promoting abrasive wear. At the same time, the generated pressure within the lubricant exceeds the design limit proposed by prostheses manufacturers, which could lead to an early failure by fatigue. Such predictions indicated that a material with similar stiffness to that of the cartilage would work more efficiently than the current polymeric replacements. Specifically, the film thickness for cartilage-like materials appears to be eight times higher and the maximum pressure three times lower than those for the current polyethylene. One of the main restrictions of Di Paolo and Berli (2006) is that their model does not consider the surface roughness, which may considerably influence polyethylene wear rates (Berli *et al.*, 2005).

In an experimental work, Kawano *et al.* (2003) induced osteoarthritis in 40 rabbits and exposed a group of them to periodic intraarticular administration of high molecular weight Hyaluronic Acid (HA). Their results showed that the administration of HA reduces the friction coefficient of damaged cartilages to the values found in healthy ones. This shows the crucial role of HA on the knee lubrication process and thus the importance of including their effects in knee prostheses models.

In this work a lubrication model of a knee prosthesis with a metallic femoral component and a tibial component with a compliant porous layer is presented. The