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INFLUENCE OF THE CONTACT MODEL ON THE DYNAMIC RESPONSE OF HUMAN KNEE JOINT

Margarida Machado, Pedro Moreira and Paulo Flores
CT2M/ Mech. Eng. Dep. - University of Minho
Campus Azurém 4800-058 Guimarães, PORTUGAL
E-mail: {margarida,pfsmoreira,pflores}@dem.uminho.pt

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EXTENDED ABSTRACT

The knee is one of the most important and requested synovial joints, which are the joints that allow larger amplitude of relative motion and so, are the painful joints of the human body. The most common knee diseases are osteoarthritis, ligamentous rupture, and meniscal tear. These pathologies usually cause anomalous contact interactions and, consequently, non-physiologic gait patterns and local pain, that could lead to a knee arthroplasty (Machado *et al.* 2010).

The contact-impact phenomenon is of paramount importance in biomechanics once it affects the motion characteristics and the integrity of the biologic structures involved. Furthermore, the design of prostheses and joint replacement systems also depend on the correct knowledge of the biological contact conditions, since the main function of these devices is to mimic the dynamic response of human joints. However, contact analysis at the knee is not a trivial task. Indeed, knee contact patterns and pressures can only be predicted by computational methods, since there is not a standard non-invasive approach to measure *in vivo* knee loads. Moreover, the dynamic response obtained from the contact analysis strongly depends on three main modeling issues: (*i*) geometrical definition of contact interfaces; (*ii*) contact points detection algorithm; (*iii*) constitutive law used to compute contact forces (Machado *et al.* 2010).

The aim of this work is to evaluate how the contact model influences the dynamic behavior of the knee. For that, it was developed a knee dynamic model based on multibody system methodologies. The model is composed by two rigid bodies, the femur and the tibia. The femur is considered fixed while the tibia rolls and slides in relation to femur on sagittal plane. An external force applied to tibia provides a dynamic activity to the model. The four main ligaments of the knee were also included in the system and modeled as nonlinear springs (Machado *et al.* 2010).The knee contact geometries were modeled using analytical regular shapes (see figure 1). The distal femur was fitted to a convex sphere. Regarding to tibia, since it exhibits a convex surface in the lateral side and a concave surface in the medial side, three different contact surfaces were adopted, namely a convex sphere, a concave sphere and a flat surface, accordingly to the study goal. (Koo and Andriacchi 2007, Machado *et al.* 2010).

(a) (b) (c)

Figure 1: Knee MRI images of (a) lateral side, (b) medial side and (c) a position between these two compartments. The fitting spherical or flat surfaces adopted for distal femur and proximal tibia in each contact scenario are represented

Moreover, since femur and tibia only present conformality at the medial compartment, different approaches to detect the contact points at knee joint were implemented. The contact at the medial side was modeled as a clearance revolute joint where the femur is the journal body and the tibia represents the bearing element. Besides, at the knee lateral compartment was considered a free contact scenario. The two contact detection methods used are based on the same assumptions, which can be sum up in two major tasks. The first task is to determine the accurate location of the potential contact points. The second task is to calculate the distance between these points and to evaluate a penetration condition in order to check if the bodies are in contact or not. The two approaches diverge at the penetration condition. For the clearance joint model, the contact exists when the eccentricity between the two bodies is greater or equal to journal radius, i.e., femur radius. Alternatively, on the free contact joint model, the presence of contact occurs when the distance between the two bodies is lesser or equal to zero. Computational simulations on the both sides of the knee were performed (figure 2) in order to evaluate the influence of the geometrical conformality on the dynamic behavior of the knee under the same loading conditions (Machado *et al.* 2010).

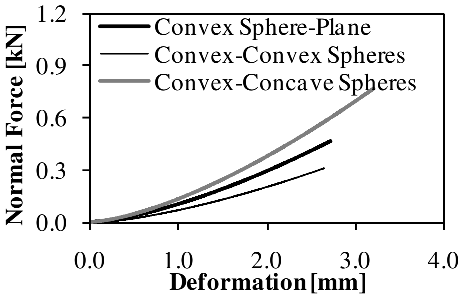

Figure 2: Normal contact force versus deformation

To compute the knee contact forces, three constitutive laws were used, namely Hertz, Hunt-Crossley and the Lankarani-Nikravesh laws. The first one is a purely elastic law and the remaining two are based on the same elasticity principles, but also include a damping factor that accounts for the energy dissipation during impact. The three contact laws were applied in the same knee contact scenario and the obtained results were compared, as shown in figure 3 (Machado *et al.* 2010).

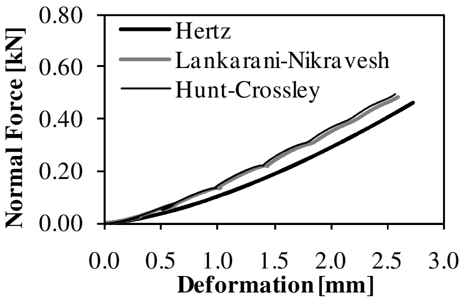

Figure 3: Normal contact force versus deformation

The contact material between the femur and the tibia, in a healthy knee articulation, is composed by a cartilage layer with approximated 4.15 mm of thickness. However, in several cases, this contact material is damaged or even replaced, as a result of a knee's pathology. For example, the knee Osteoarthritis (OA) causes cartilage degeneration and the progressive reduction of its volume. As well, sometimes the patient suffers also from Osteoporosis (OP), which is characterized by the loosing of bone mechanical properties. Furthermore, the artificial knees present also contact materials with different properties from cartilage, which also affects the dynamic response of the joint. Thus, in this work, six contact material conditions were considered: one for healthy knee, three for pathologic knees and two for knee prostheses.

For the healthy knee model, a normal cartilage layer with 4.15 mm of thickness was considered. Regarding to the pathologic knees, three advanced osteoarthritis knee stages were modeled, namely 90%OA, 90%OA+OP and 100%OA. For the 90%OA, a double contact layer was adopted, which is composed by a thin cartilage layer with 0.415 mm of thickness and natural bone. The 90%OA+OP is similar to the 90%OA model, but instead of having natural bone as the second contact layer, has osteoporotic bone. At the 100%OA model, the cartilage layer is totally neglected and only a natural bone surface is considered as contact material. In what concerns to artificial knees, it was modeled a Ti-UHMWPE prosthesis and also a Ti-Ti prosthesis, in order to compare the performance of a polymeric tibial insert against a metallic one. Computational simulations were carried out using the same geometrical model and contact law. The obtained results for the three knee models with cartilage are plotted in figure 4. The remaining results for the other three knee models without cartilage are illustrated in figure 5.

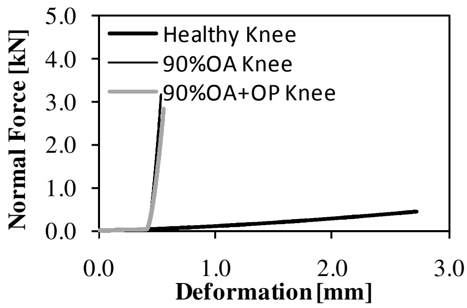

Figure 4: Normal contact force versus deformation

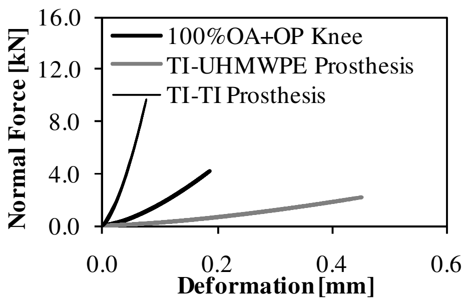

Figure 5: Normal contact force versus deformation

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