World Academy of Science, Engineering and Technology
International Journal of Materials and Metallurgical Engineering
Vol:11, No:04, 2017

Visco-Hyperelastic Finite Element Analysis for Diagnosis of Knee Joint Injury Caused by Meniscal Tearing

Authors : Eiji Nakamachi, Tsuyoshi Eguchi, Sayo Yamamoto, Yusuke Morita, H. Sakamoto

Abstract : In this study, we aim to reveal the relationship between the meniscal tearing and the articular cartilage injury of knee joint by using the dynamic explicit finite element (FE) method. Meniscal injuries reduce its functional ability and consequently increase the load on the articular cartilage of knee joint. In order to prevent the induction of osteoarthritis (OA) caused by meniscal injuries, many medical treatment techniques, such as artificial meniscus replacement and meniscal regeneration, have been developed. However, it is reported that these treatments are not the comprehensive methods. In order to reveal the fundamental mechanism of OA induction, the mechanical characterization of meniscus under the condition of normal and injured states is carried out by using FE analyses. At first, a FE model of the human knee joint in the case of normal state – 'intact' - was constructed by using the magnetron resonance (MR) tomography images and the image construction code, Materialize Mimics. Next, two types of meniscal injury models with the radial tears of medial and lateral menisci were constructed. In FE analyses, the linear elastic constitutive law was adopted for the femur and tibia bones, the visco-hyperelastic constitutive law for the articular cartilage, and the visco-anisotropic hyperelastic constitutive law for the meniscus, respectively. Material properties of articular cartilage and meniscus were identified using the stress-strain curves obtained by our compressive and the tensile tests. The numerical results under the normal walking condition revealed how and where the maximum compressive stress occurred on the articular cartilage. The maximum compressive stress and its occurrence point were varied in the intact and two meniscal tear models. These compressive stress values can be used to establish the threshold value to cause the pathological change for the diagnosis. In this study, FE analyses of knee joint were carried out to reveal the influence of meniscal injuries on the cartilage injury. The following conclusions are obtained. 1. 3D FE model, which consists femur, tibia, articular cartilage and meniscus was constructed based on MR images of human knee joint. The image processing code, Materialize Mimics was used by using the tetrahedral FE elements. 2. Visco-anisotropic hyperelastic constitutive equation was formulated by adopting the generalized Kelvin model. The material properties of meniscus and articular cartilage were determined by curve fitting with experimental results. 3. Stresses on the articular cartilage and menisci were obtained in cases of the intact and two radial tears of medial and lateral menisci. Through comparison with the case of intact knee joint, two tear models show almost same stress value and higher value than the intact one. It was shown that both meniscal tears induce the stress localization in both medial and lateral regions. It is confirmed that our newly developed FE analysis code has a potential to be a new diagnostic system to evaluate the meniscal damage on the articular cartilage through the mechanical functional assessment.

Keywords : finite element analysis, hyperelastic constitutive law, knee joint injury, meniscal tear, stress concentration
Conference Title : ICMET 2017 : International Conference on Materials and Engineering Technology
Conference Location : Lisbon, Portugal
Conference Dates : April 16-17, 2017