Proceedings of the Canadian Society for Mechanical Engineering International Congress 2022
CSME Congress 2022
June 5-8, 2022, Edmonton, AB, Canada

CHARACTERIZING REGION-DEPENDENT PROPERTIES OF ARTICULAR CARTILAGE USING MACHINE LEARNING

Erfan Hamsayeh Abbasi Niasar, Leping Li*
Department of Mechanical and Manufacturing Engineering, University of Calgary, Calgary, Canada
*leping.li@ucalgary.ca

ABSTRACT

Articular cartilage is shown to deteriorate with the onset of knee osteoarthritis (OA). Characterizing the changes is of utmost importance as it is necessary for early detection of OA. Previous studies have investigated the tissue inhomogeneity associated with zonal differences across the depth of cartilage. The objective of this study is to investigate regional variabilities of cartilage properties across the articular surface of the joint. Indentation tests were carried out to map the viscoelastic behavior of articular cartilage over the entire surface with a 2-mm spherical indenter. Compression rates of 0.2-0.4 mm/s were applied, following by a 100s relaxation. Twelve intact porcine knees were purchased and dissected for harvesting four cartilage-bone specimens from each joint, namely lateral femoral, medial femoral, lateral tibial, and medial tibial cartilages. The samples were immersed in PBS and kept in the fridge before the test. Nine full sets and three partial sets of data were successfully collected. A finite element (FE) model of the indentation test was developed in ABAQUS to extract the material properties of cartilage through curve-fitting, where a previously validated poromechanical tissue model was implemented. The extracted material properties of cartilage are the elastic modulus (E_m) and Poisson's ratio of the nonfibrillar matrix, the nonlinear modulus of the fibrillar matrix ($E_f = E_0 + E_\varepsilon \varepsilon$), and the tissue permeability (k). K-means clustering algorithm along with the elbow method were used to quantify the number of regions or clusters required to characterize the regional differences for each specimen. Four regions for the medial tibial plateau and three regions for the other three specimens were found to be the ideal number of regions, making a total of thirteen regions for knee joint cartilages. A good agreement was reached between the FE and experimental curve-fitting results with the errors falling below 10%. A deviation in the range of 25-40% was seen when comparing the material properties extracted for distinct regions to the average over the whole specimen, e.g., lateral femoral cartilage. For instance, the material properties for lateral tibial cartilage were in the following range: E_m = 0.15-0.28 MPa; E_{0x} = 1.06-1.85 MPa; E_ε = 443-725 MPa; k = 1.7-2.5($\times 10^{-3}$) mm^4/Ns. The proposed methodology in this study may pave the way for an in-depth understanding of the region-dependent cartilage properties of human knees, which will facilitate OA modelling, e.g., they can be used as the input for finite element or mechanobiology models.