STUDY OF THE LOCATIONS AND MORPHOLOGY OF ISOLATED KNEE FOCAL CARTILAGE DEFECTS USING A STATISTICAL SHAPE MODELING APPROACH

Majid Mohammad Sadeghi (1), Erkan Aşık (2), Pieter Emans (1,2), Nazli Tümer (3), Gabrielle Tuijthof (4), Alex Roth (1,2)

1. Department of Orthopedic Surgery, Maastricht UMC+, The Netherlands; 2. Avalanche Medical BV, Maastricht, The Netherlands; 3. Department of Biomaterials & Tissue Biomechanics, Delft University of Technology, The Netherlands; 4. Department of Biomechanical Engineering, University of Twente, The Netherlands

Introduction

Focal knee resurfacing implants (FKRIs) are an emerging alternative treatment for knee focal cartilage injuries. FKRIs are typically intended for the middle-aged population where biological cartilage procedures and total knee replacement are not proper options due to longevity concerns. The objective of a FKRI is to restore the articular cartilage surface to its native morphology in order to restore peak contact stress levels to healthy physiological levels. The design of an off-the-shelf FKRI thus requires detailed information about the most commonly occurring defect locations and the local morphology at these defect locations. The objectives of this work are threefold: (1) to develop a statistical shape model (SSM) of the distal femoral cartilage surface that captures morphology variation across the population, (2) to develop a heat map of cartilage defect locations to identify the areas where the local morphology needs to be characterized, and (3) to characterize the local articular cartilage surface morphology at the sites where cartilage defects commonly occur.

Methods

Magnetic Resonance Imaging (MRI) scans of 58 patients who were determined to be eligible for FKRI surgery were selected to be used for creating the SSM and heat map. The cartilage models were semi-automatically segmented from the MRI scans. Registration algorithms were used to find the point-to-point correspondence of the models. Models were translated and reoriented to a reference location to remove the relative differences in pose which are not related to the variation of the shapes. Principle component analysis was used to find the modes of variation within the population. The resulting statistical shape model was evaluated by investigating its compactness and accuracy [1]. To create the heat map, locally isolated cartilage defect models were manually segmented from MRI images. Segmented 3D mesh models were then aligned to the average shape of cartilage as created using SSM. This alignment step uses the same transformation matrices found during the alignment of the corresponding cartilage models while creating the SSM. The aligned overlap of the defect models shows the probability of damage occurrence at different locations on the average cartilage surface (Figure 1). To characterize the surface morphology of the healthy cartilage at defect locations, the local radius of curvatures are calculated by fitting a circle to the surface of the average SSM shape in anteroposterior and mediolateral directions at those defect locations (Figure 1).

Results

The compactness of the SSM model constructed from 58 patients shows that the first 10 modes cover 95 percent of the variation of the data. The accuracy of the SSM model is 0.37 mm which is below the input MRI data voxel size of 1.0 x 0.5 x 0.5 mm. The cartilage defect location heat map shows a concentration of defects on the medial condyle corresponding with the site of peak contact pressure during the stance phase of the gait cycle (Figure 1). The anteroposterior and mediolateral radius of curvatures of the cartilage surface measured from the average SSM shape on the observed hottest point were determined to be 23 and 38 mm respectively.

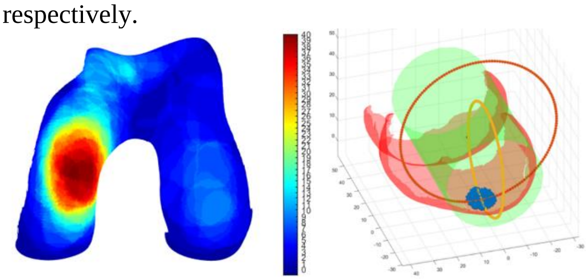

Figure 1: Left) Defect location heat map showing the distribution of defects over the cartilage surface, Right) Measuring radius of curvatures on a defect location.

Discussion

This workflow proves to provide detailed information on the isolated focal knee cartilage defects with the required level of detail to enable FKRI design. A higher number of cases needs to be included to increase the heat map accuracy on lateral condyle and trochlea areas. To validate the use of the extracted implant design parameters, implant fit evaluation in a population sample set created using the SSM should be performed. This work may also be useful for guiding regenerative medicine or allografting approaches in cartilage repair.

References

1. Sarkalkan N, Weinans H, Zadpoor AA. Statistical shape and appearance models of bones. Bone. 2014 Mar;60:129-40.