# TOWARDS PREDICTING THE DISCRETE GRADES FOR PROGRESSIVE CHANGES OF KNEE OSTEOARTHRITIS: A FINITE ELEMENT STUDY

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## Introduction

Abnormal loading in the knee joint may lead to degenerative changes of articular cartilage [1]. Finite element models are used to simulate mechanical responses of joint tissues that can be utilized to predict tissues' future condition [2]. However, the method we previously developed in [2] lacks evaluation of the relationship between the discrete Kellgren-Lawrence (KL) grading classifications, which is based on radiologic features of osteoarthritis (OA), and quantifiable continuous changes in OA, i.e., joint space narrowing (JSN). In this study, we tested if cartilage overexposure of healthy joints at the baseline can be used to predict knee osteoarthritis grades while correlating with JSN after an 8-year follow-up.

## Methods

We obtained information from 103 subjects in the Osteoarthritis Initiative database. At baseline time, the subjects were less than 70 years of age with a BMI under 35 kg/m$^2$ and had both knees healthy. One knee per individual developed OA during the 8-year follow-up while the other remained healthy. All knees were grouped by the radiographic OA grade (KL) at the 8-year follow-up time; 29 stayed healthy (KL0,1), 38 developed mild OA (KL2), and 36 developed severe OA (KL3,4). We created personalized knee finite element models for the medial and lateral tibiofemoral compartments using baseline information and simulated a simplified gait loading [2] (Fig. 1).

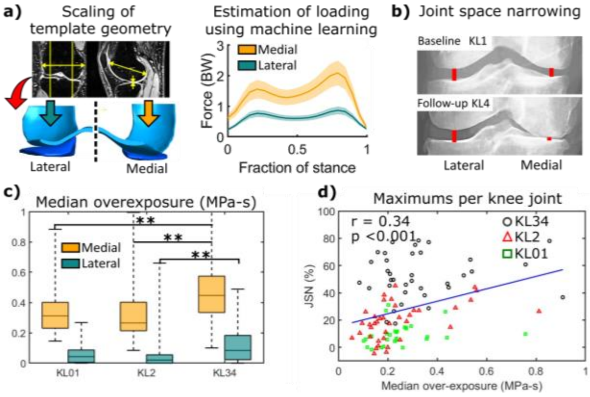


*Figure 1: a) Knee finite element models. b) Joint space measurement from X-rays at the baseline and 8-year follow-up. c) Median of simulated overexposure in joint compartments. d)Maximums of joint space narrowing vs overexposure. Whiskers show ranges. ** p < 0.01.*

We used femoral medial-lateral and maximum anterior-posterior distances, and cartilage thickness from MRIs to scale the compartment template geometries; while sex, weight, age, height, walking speed, and joint alignment were used to estimate the peak joint contact forces by a neural network trained with musculoskeletal models' results (r = 0.64) [3]. The overexposure corresponds to the sum of the overstress (with respect to age-dependent degeneration thresholds of tensile stress) times its duration in each model's element over the stance phase of the gait. The JSN was defined as the percent change in joint space measured with the aid of an in-house MATLAB tool on frontal X-rays between baseline and follow-up times. Knee models used a biphasic fibril-reinforced cartilage formulation in FEBio software. For comparisons of overexposures to predict future KL grades and JSN, we used non-parametric statistical tests and Pearson correlations in MATLAB.

## Results

Healthy and mildly affected joints differed from the severely affected joints (Fig. 1c), as determined either with the simulated over-exposure or the measured JSN. Medial compartment values were higher than lateral in the FE model ($p < 0.001$) in all KL groups, but only in KL2 for the JSN ($p = 0.03$). Over-exposure and JSN of matching knees did not linearly correlate either for the medial ($r = 0.14$, $p = 0.15$) or lateral ($r = 0.18$, $p = 0.07$) compartments, but only by taking the maximum values per knee compartment ($r = 0.34$, $p < 0.001$, Fig. 1d).

## Discussion

The results suggest that articular cartilage overexposure may be used to predict the future radiographic OA grade of the whole joint, while one value per knee correlates with the maximum JSN experienced. Compartment-wise validations are needed since we used unique KL values per knee. The low correlations observed can be explained in part by the uncertainties in JSN calculations due to the variability in X-ray imaging alignment from baseline to follow-up. In addition, our method does not consider alterations in loading while OA progresses [4], which may increase cartilage overexposure in other regions, affecting the correlations observed. We foresee the need to incorporate tissue adaptation [5] into our pipeline to investigate mechanisms of cartilage thinning.

## References

1. Allen K. et al., Curr Opin Rheumatol, 3: 276-283,2015.
2. Mononen M. et al, Ann Biomed Eng, 47:813-825, 2018.
3. Lavikainen, J. et al., ORS Annual Meeting 2022, #1855.
4. Meireles S. el al., Plos One, 12(11): e0187583, 2017
5. Miller. R et al., PeerJ, J 8:e9676, 2020.

## Acknowledgments

To the Finnish Cultural Foundation, Academy of Finland (324994, 328920, 324529), and Sigrid Juselius Foundation.