# CONTACT-PRESSURE BASED, MULTI-SCALE KNEE MODEL TO PREDICT CARTILAGE DEGENERATION

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## Introduction

Osteoarthritis (OA) is a whole joint disease, which most frequently affects the knee joint [1]. Cartilage degeneration is the hallmark of OA, however, the mechano-biological responses of cartilage during OA are not yet fully understood [2]. To increase understanding on cartilage degeneration, we recently developed a whole knee joint finite element (FE) models (including the femoral and tibial cartilages and menisci) that predicts cartilage degeneration based on loading conditions obtained from MSK modeling and integrated 3D motion capture data. However, the complexity and high computational costs prohibit these models to be used with adaptive algorithms, that requires to iteratively run the FE models to predict the time-dependent tissue degradation [3]. In this study, the validity of an FE model of the tibial medial compartment for prediction of cartilage degeneration based on contact-pressure estimation obtained from a MSK modeling workflow is verified for a healthy and progressive knee OA subjects against the whole joint FE models (gold standard). The reduced model efficiently predicts cartilage degeneration, which is promising to be used for adaptive modeling in the future.

## Methods

Comparable to the original whole joint FE model, an FE model of the medial tibial compartment was built using fibril-reinforced poroviscoelestic material. The pressure distributions estimated by musculoskeletal models [4], based on 3D integrated gait data captured from a healthy (control) and a progressive knee OA subject were applied to the FE model. Fibril strain (FS) and maximum shear strain (MSS), were calculated in both models at the first peak of knee contact force. The normalized volumes of degraded elements and degrees of collagen and PG degradations were estimated with previously introduced degradation equations (Eqs. 1 and 2) [3].

$$Deg_{collagen} = 1 - e^{-|FS - threshold_{FS}|} \quad (1)$$

$$Deg_{PG} = \frac{1}{3}\sqrt{|MSS - threshold_{MSS}|} \quad (2)$$

## Results

Computational cost estimated from the reduced model decreased by 8 times compared to the whole joint model (2h vs 16h). FS and MSS obtained from both models are visualized in Fig.1. The volume of degenerated elements and the average degrees of collagen degeneration (threshold: FS=10%) are given in Table 1. The degrees of PG degeneration are given for two thresholds (MSS=30% or 50%) [3,5].

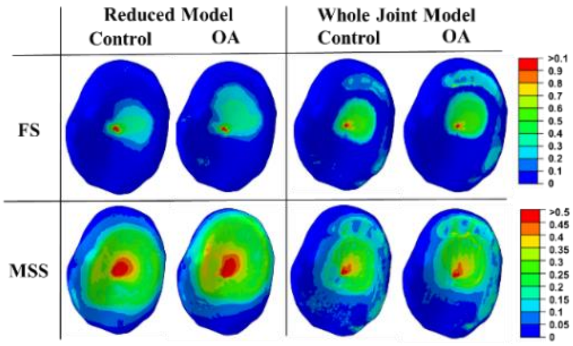


*Figure 1: Comparison of fibril strain (FS) and maximum shear strain (MSS) in medial tibial cartilage obtained from reduced and whole joint model.*

| Degradation Parameters | | Control | | OA | |
|---|---|---|---|---|---|
| | | V% | D% | V% | D% |
| Reduced Model | Collagen | 0 | N/A | 0 | N/A |
| | $PG_{thresh\ 30\%}$ | 17.7 | 6.67 | 28.9 | 6.57 |
| | $PG_{thresh\ 50\%}$ | 0.12 | 7.55 | 0.05 | 7.38 |
| Whole Joint Model | Collagen | 0.03 | 0.92 | 0.02 | 0.63 |
| | $PG_{thresh\ 30\%}$ | 4.37 | 4.66 | 8.13 | 5.27 |
| | $PG_{thresh\ 50\%}$ | 0.02 | 7.77 | 0.01 | 6.45 |

*Table 1: Percentages of volume (V) and degree (D) of collagen and PG degradation.*

## Discussion

Larger areas of high FS and MSS are obtained for the OA compared to the control subject in both reduced and whole joint models (Fig. 1). The predicted locations of high FS and MSS are comparable between the two models, however, higher MSS are observed in the reduced model. This caused overestimating the degree and volume of PG degradation in the reduced model (Table 1), which can be due to excluding the role of the menisci, as an energy absorber tissue decreasing the pressure on cartilage. Therefore, the reduced model can correctly predict the location of degradation but may overestimate the degradation level. Additionally, the sensitivity of predicted PG depletion to the threshold suggests the needs for more accurate estimation of degradation thresholds in adaptive models.

## References

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