Computational modeling can predict onset and progression of knee osteoarthritis in overweight people

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Computational modelling makes it possible to predict the onset and progression of knee osteoarthritis in overweight people, shows a new study from the University of Eastern Finland. A computational model based on the degradation of the collagen fibril network in the articular cartilage was able to predict the onset and progression of osteoarthritis in overweight people during a four-year follow-up. In normal-weight people, osteoarthritis did not develop within this time span.

The study also developed a model of the knee joint which makes it possible to evaluate the mechanical responses experienced by cartilage cells in healthy and osteoarthritic cartilage during daily activities such as walking. The model demonstrated that both menisectomy and osteoarthritic changes to the cartilage cause significant alterations in cartilage cell responses.

Osteoarthritis is a joint disease estimated to affect around 5% of the total world population. Osteoarthritis is the most common in the knee or hip joint and it often develops as a result of ageing, but it can also develop due to excessive loading or joint injury. In Europe, over 100 million people have arthritis, and in America, direct costs of arthritis were $51.1 billion in 2004. In addition, it has been predicted that the number of patients with knee osteoarthritis increases by 40% by the end of 2050.

Osteoarthritis proceeds gradually, weakening the articular cartilage and ultimately wearing it off completely from the ends of articulating bones. In these cases, the patient suffers from heavy joint pain and the joint becomes stiff, often leading to incapacity for work. Joint replacement surgery is the only effective treatment for osteoarthritis, which is why the prevention of osteoarthritis would be a cost-effective alternative both for the patient and society at large.

Simulation methods developed may find use in specialised health care in the future

The study utilised a computational modelling method integrating the tissue and cellular levels of the articular cartilage in order to analyse the function of the articular cartilage during the onset and progression of osteoarthritis. The method simulated the effect of articular cartilage composition, structure and various loadings on the volume, shape and mechanical responses of cartilage cells.

Compared to healthy cartilage, the cell volume of osteoarthritic cartilage increased as a result of mechanical loading. The modelling indicated that the most important explanatory factors for the cell volume increase were the pericellular fixed charge density, i.e. the number of proteoglycan molecules, and the stiffness of the collagen fibril network.

The study also analysed the effect of menisectomy, a commonly used method in knee surgery, and simulated overweight on cell responses. Both menisectomy and simulated overweight substantially increased fluid pressures in the cell and cartilage tissue during walking, but they did not have an effect on the cell shape or volume in healthy cartilage. In osteoarthritic cartilage, however, cells were compressed and elongated more, probably due to altered cartilage integrity.

During standing, the strains were amplified more in the cell than in pericellullar tissue in healthy joint cartilages, but the opposite was observed in osteoarthritic joint cartilage. It is possible that the pericellular tissue's function is to protect cartilage cells from sudden changes and to promote cartilage health.

The study also developed computational algorithms for the degradation of the collagen fibril network in the articular cartilage and its reorganisation in order to predict the development and progression of osteoarthritis caused by overweight and cartilage damage. The estimate obtained from the degradation algorithm was well in line with the clinically observed progression of osteoarthritis during a four-year follow-up. Furthermore, the collagen fibril network structure in the mechanically injured cartilage was observed to be disorganised in the vicinity of the injury, suggesting that a cartilage injury exposes cartilage to further damage.

In-depth understanding of the effects of abnormal loading, early osteoarthritis and mechanical injuries on cellular and tissue responses in cartilage makes it possible to develop new strategies for the recognition, prevention and slowing down the progression of the disease. The methods developed in the study may become widespread in specialised health care in the future. However, rigorous clinical validation will be necessary before they can be introduced to clinical use.

More information: Mika E. Mononen et al, A Novel Method to Simulate the Progression of Collagen Degeneration of Cartilage in the Knee: Data from the Osteoarthritis Initiative, *Scientific Reports* (2016). DOI: 10.1038/srep21415

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