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SCAFFOLD GEOMETRY INFLUENCES THE MECHANICAL PROPERTIES OF TISSUE ENGINEERED CARTILAGE

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INTRODUCTION:

Tissue engineered (TE) cartilage aims to mimic the native cartilage extracellular matrix (ECM) distribution and mechanical properties by culturing chondrocytes onto biocompatible and biodegradable porous scaffolds under proper supplementation and mechanical regimes [1]. The scaffolds are often small cylinders with uniform cell seeding. However, this approach yields tissues with stiffer peripheries and softer cores due to insufficient nutrient supply to the centre of the constructs, resulting in cell death and reduced ECM production [1]. The introduction of channels in the constructs has increased ECM accumulation in the centre of the scaffolds and mechanical properties [1]. On this study we simulated the influence of the introduction of a central channel in cylindrical or rectangular TE cartilage constructs on nutrient supply, cell density, ECM concentration and distribution and biphasic mechanical properties such as the Young’s modulus and permeability.

METHODS:

Biphasic models consisting of a solid elastic matrix with permeability were developed in Abaqus [2]. Scaffolds were initially modelled as cylinders (8mm diameter x 5mm height) or rectangles (8mm side x 5mm height). A single cylindrical channel (2mm diameter) was introduced in cylindrical and rectangular scaffolds, while a rectangular channel (2mm side) was introduced in a rectangular scaffold. All scaffolds had an initial uniform cell density of 16 x 10^6 cells/ml. The models were meshed with approximately 5000 pore pressure-stress-temperature elements. The initial mechanical properties were: E=40 kPa; υ=0.35; k= 5 x 10^{-12} $m^4N^{-1}s^{-1}$. The dynamics of nutrient concentration, cell density, ECM concentration and mechanical properties were modelled using Fortran user subroutines. A static culture period of 72h was simulated.

RESULTS AND DISCUSSION:

The introduction of a central channel led to an approximately 10-fold increase in glucose concentration in the inner regions of the constructs and a 100-fold increase in oxygen. The enhancement of nutrient supply increased global cell densities by 9%, and ECM concentrations by 50%. The final distributions of the Young's modulus and permeability are shown in Figure 1.

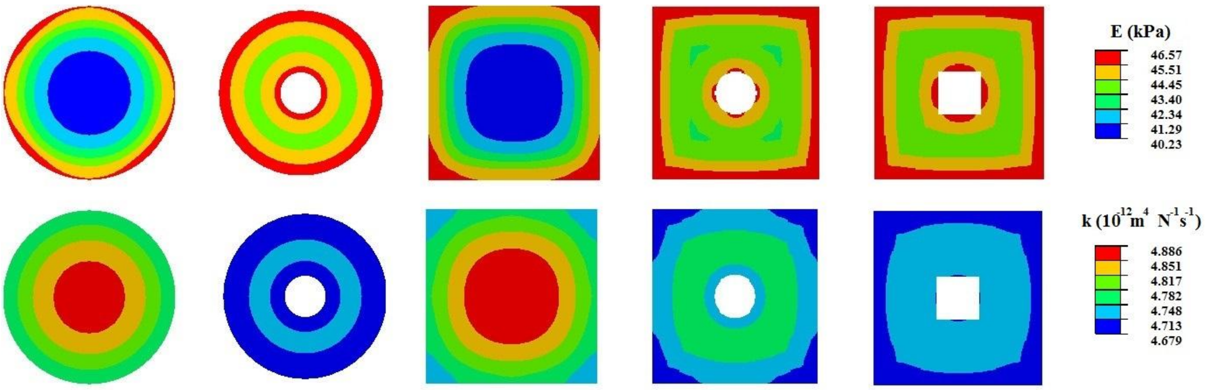

Figure 1. Distributions of the Young's modulus (upper panel) and permeability (lower panel) in a transverse cut of the five tested geometries after 72h of static culture simulation.

The introduction of a central channel has produced more homogeneous distributions of the mechanical parameters when compared with their full counterparts. The introduction of the channels led to an average increase of 4% in the Young's modulus and 2% decrease of permeability. The rectangular channel yielded better results than the cylindrical one in the rectangular scaffolds. Since the ECM concentrations after 72h are still very low (below 0.1% w/w), the large relative increase in ECM concentration led to small improvements in the mechanical properties. In conclusion, by decreasing the nutrient diffusion path length, the biomechanical outputs and properties are increased. Cultures with much longer periods, as well as mechanical stimuli, are required to approximate the mechanical properties of these constructs to the native cartilage ones (E=450-800 kPa, $k=10^{-15}$-10^{-16} $m^4N^{-1}s^{-1}$) [3].

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