DETERMINATION OF MATERIAL PARAMETERS OF SCAFFOLD-FREE CARTILAGE TRANSPLANTS IN DEPENDENCE OF THEIR CULTIVATION

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Introduction

Artificial cartilage can be investigated and characterized by biomechanical, biochemical, and histological analysis. The biomechanical properties contain a variety of relevant information for the functional characterization of cartilaginous tissue. Thus, the characterizations are usually carried out at the end of the cultivation time [1]. To better assess the maturity level of 3D scaffold-free cartilage transplants (SFCT), the article aims to identify and discuss correlations between biomechanical material parameters and cultivation conditions (time and mechanical stimulation). For this study, an optimized biphasic 3D Finite-Element (FE) modeling approach with tension-compression nonlinearity was implemented to determine the material parameters of SFCT [2].

Methods

The equine chondrocytes of the stifle joint were used for the production of SFCT. After cultivation and proliferation in monolayer cultures, cells were transferred into a three-dimensional structure without any artificial matrix, growth, or differentiation factors. In order to produce SFCT and the extracellular matrix, the samples were manually exposed to undifferentiated cyclic mechanical pressure (CMP). The duration, frequency, and intensity of pressure were determined under tactile and visual control [3]. The SFCT (n = 18) were analysed after 1 (0-fold CMP), 3 (5-fold CMP) and 6 (14-fold CMP) weeks of culturing. Chondrogenesis in SFCT was documented by macroscopic, biochemical, histological, and biomechanical analysis. For biomechanical investigations, Young's modulus E, fibre modulus ξ and permeability k of samples were determined using uniaxial relaxation compression tests and a FE parameter identification routine [2]. The relaxation tests of the specimens were executed with a testing velocity of v = 0.02 mm/s, an initial load of F = 0.1 N, a relaxation time of t = 3400 s and a strain of 20 % [4]. For the computational approach, an optimised 3D FE-based method was determined to identify the biomechanical parameters (Figure 1a). The SFCTs were modelled with a compressible isotropic neo-Hooke's ground matrix reinforced with a spherical fibre distribution and constant permeability [2,4].

Results

For the parameter identification of SFCT, the 3D FE-model with an extended biphasic material model yields a $R^2 > 0.94$ (Figure 1b). The linear correlation results clearly demonstrate that the biomechanical parameters E ($R^2 = 0.82$, $p < 0.05$), ξ ($R^2 = 0.75$, $p < 0.05$) and k ($R^2 = -0.74$, $p < 0.05$) correlate strongly with the cultivation conditions. The parameter k indicates negative, the other parameters show positive correlations. Table 1 shows the calculated parameters. The Young's modulus and fibre modulus increase with increasing cultivation time and CMP, while permeability decreases.

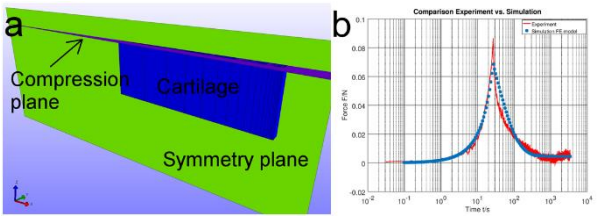

Figure 1: Optimized FE-model for the parameter identification (a) and fit result (b).

Cultivation Time / CMP	E [kPa]	ξ [kPa]	k [mm⁴/Ns]
1 week / 0-fold	0.29	0.65	11.68
3 weeks / 5-fold	1.12	1.07	1.90
6 weeks / 14-fold	2.34	1.38	1.49

Table 1: Calculated material parameters (Median) as a function of the cultivation time and CMP.

Discussion

These results show that linear correlations between biomechanical parameters and cultivation conditions exist. Therefore, it is possible to characterize the maturity level of the SFCT. At the beginning of the cultivation time, the maturity level of the SFCT is very low. With increasing CMP and cultivation time, the stiffness of the SFCT increases and thus the maturity level. Future work will extend the correlations with parameters from the biochemical and histological analyses. Furthermore, the influence of mechanical stimulation will be analyzed in more depth. The optimized FE-model routine operated robustly. In addition, appropriate material models for SFCT will be developed and integrated in the FE-model.

References

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