Micro-CT/micromechanics-based Finite Element model

A 71 volume-% macroporous tissue engineering scaffold made of poly-l-lactide (PLLA) with 10 mass-% of pseudo-spherical tri-calcium phosphate (TCP) inclusions (diameters in the range of several nanometers) was micro-CT-scanned. The corresponding stack of images was converted into regular Finite Element (FE) models consisting of around 100,000 to 1,000,000 finite elements, as described in [Dejaco et al. (2012)]. Therefore, the attenuation-related, voxel-specific grey values were converted into TCP-contents in a way similar to that described in [Dejaco et al. (2011), Scheiner et al. (2009)], and the latter, together with nonindentation tests evaluated according to [Oliver and Pharr (1992)], entered a homogenization scheme of the Mori-Tanaka type, as to deliver voxel-specific (and hence, finite element-specific) elastic properties.

Reliable determination of elasticity from micro-CT images and micromechanics

We have recently proposed [Scheiner et al. 2009; Dejaco et al. 2012] to translate the X-ray attenuation-related grey values making up a microCT image, into voxel-specific (nano)porosities, and to resolve the microstructure (or nanostructure) within each finite element in terms of a continuum micromechanics representation [Fritsch et al. (2009)] linking (nano)porosity to material properties, as to arrive at tissue property maps across the entire imaged scaffold. These property maps turned out as reasonable input for FE simulations [Scheiner et al. (2009); Dejaco et al. (2012)]. In the present work, we extend this strategy to rapid-prototyped polymer-ceramic scaffolds (Swieszkowski et al. (2007)). Additionally quasi-static unloading tests are performed to validate the FE-model-derived values for Young’s modulus.

Materials and Methods

Conversion of micro-CT data into volume fractions

X-ray attenuation coefficient of PLLA-TCP composite:

\[ \mu = \frac{\text{PLLA}}{\text{TCP}} + \frac{\text{TCP}}{\text{TCP}} \]

Grey value is linearly related to attenuation:

\[ GV = GV_{\text{PLLA}} + GV_{\text{TCP}} \]

TCP volume fraction as a function of grey value:

\[ f_{\text{TCP}} = \frac{GV - GV_{\text{PLLA}}}{GV_{\text{TCP}}} \]

Effective stiffness of the solid phase as a function of grey value computed, using a representative volume element (RVE) of composite solid phase:

\[ E_{\text{eff}} = \frac{F}{A \cdot S} = 1.429 \pm 0.27 \text{ MPa} \]

Young’s modulus

\[ E_{\text{TCP}} = \frac{1}{2} \left( E_{\text{TCP}} + E_{\text{PLLA}} \right) \]

Poisson’s ratio

\[ \nu_{\text{TCP}} = \frac{v_{\text{TCP}} + v_{\text{PLLA}}}{2} \]

Force-displacement curves were recorded throughout consecutive loading-unloading cycles up to a maximum nominal strain of -0.02, -0.03, -0.04 and -0.05, with a strain rate of 0.005 s⁻¹, and the unloading regimes of these curves were evaluated. From the load maxima at the maximum applied strain levels and the corresponding displacements, the unloading curve was followed for a minimum of 50 µm along the displacement axis, and a maximum of 350 µm, in 50 µm intervals. These unloading portions were checked with respect to their linearity (indicating linear elastic properties), in terms of R², the coefficient of determination between the measured forces and displacements. The slopes S of all unloading portions with R² > 0.90 are used to determine the Young’s modulus of the macroporous scaffold.