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MicroCT-based fracture risk assessment in ceramic bone tissue engineering constructs: intravoxel micromechanics for large-scale FE simulations

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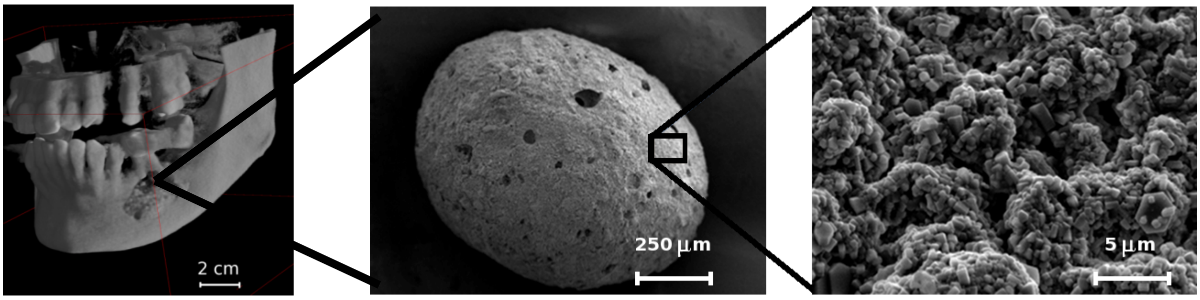

Figure 1: Illustration of application of hydroxyapatite granules to repair bone-defects in human bone (left), scanning electron micrographs (SEM) of porous granule of carbonate-containing hydroxyapatite (middle) and nanoporous polycrystal building up the granule (right).

Hundred micrometers-sized porous hydroxyapatite globules [1] have proved as successful tissue engineering strategy for mandibular bone defects in vivo (see Fig. 1). These granules need to provide enough porous space for bone ingrowth, while maintaining sufficient mechanical competence. Detailled multiscale mechanics simulations based on microCT information may open new ways for globule optimization. Therefore, we start with a micro-Computed Tomography (micro-CT) image of the object, and first translate, based on the average rule for X-ray attenuation coefficients [3], the voxel-specific attenuation values into voxel-specific nanoporosities, whereby we consider, as independent experimental input, the granule's mass and volume as well as the mass density of hydroxyapatite [4]. Subsequently, we use semi-analytical random homogenization methods [5] to predict the elasticity and brittle strength of RVEs of several microns characteristic length, from the elastic properties of single elongated hydroxyapatite crystals and the nanoporosity in between [6] in a voxel-specific manner. They enter large-scale Finite Element analyses of a "splitting test", where one globule is loaded at its poles. When comparing the corresponding results to analytical results for a crack-free sphere loaded at its poles, we understand that the cracks weaken the structure by one to two orders of magnitudes. Moreover, a highly parallelized computer-system allows for micromechanics-based intra-element stress analysis (see Figure 2), providing maps of local fracture risk.

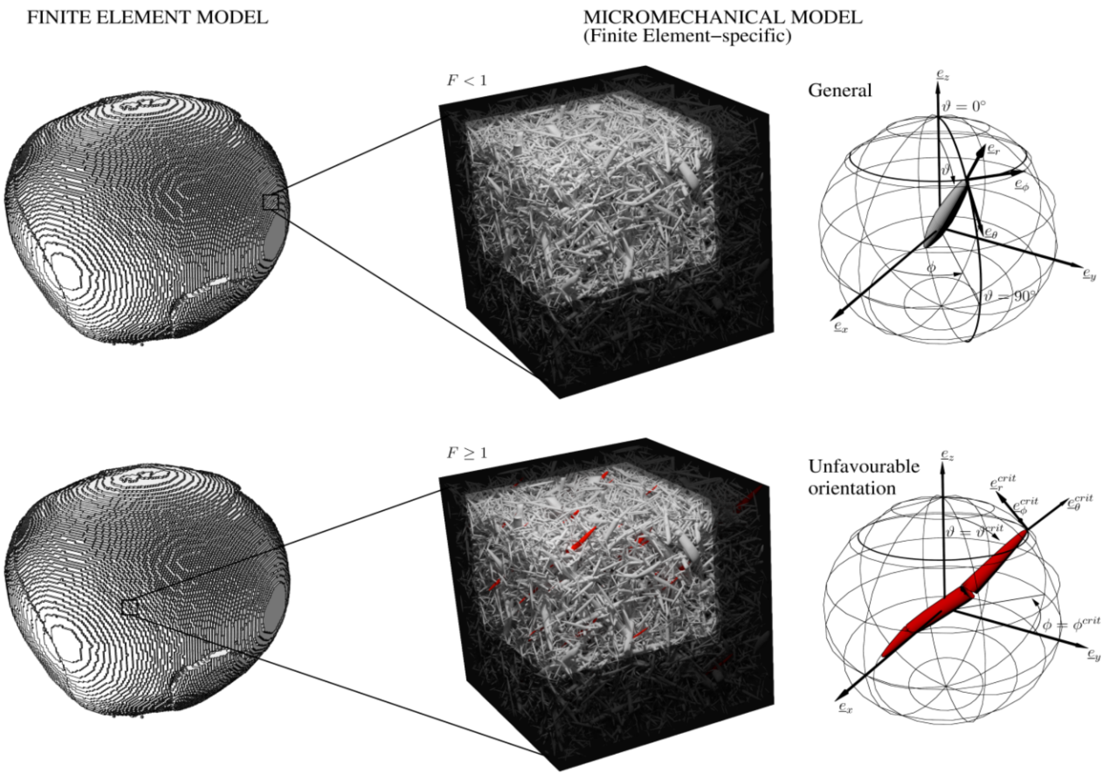

Figure 2: Intra-element micromechanics: each finite element of the meshes depicted in the left is composed of hydroxyapatite needles oriented in all spatial directions (middle), and the most unfavorably stressed needle may break and trigger overall material failure at the element level.

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