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RAPID, PATIENT SPECIFIC OPTIMIZATION OF BONE SCAFFOLDS

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Summary: We first present a simple, efficient, three dimensional, time dependent model for bone regeneration in the presence of porous scaffolds to bridge critical size bone defects. The essential processes are an interplay between the mechanical and biological environment which we model by a coupled system of PDEs and ODEs. The mechanical environment is represented by a linear elastic equation and the biological environment through reaction-diffusion equations as well as logistic ODEs, modelling signaling molecules and cells/bone respectively. Material properties are incorporated using homogenized quantities not resolving any scaffold microstructure. This makes the model efficient in computations, thus suitable as a forward equation in optimization algorithms and opening up the possibility of patient specific scaffold design in the sense of precision medicine. The model can take into account patient specific parameter, for example the defect geometry or the rate of bone regeneration. Our numerical findings show that our model for example recovers and quantifies clinically relevant stress shielding effects that appear in vivo due to external fixation of the scaffold at the defect site. In the second part, we use this model as a PDE constraint for the optimization of polymer scaffold porosities. The result of the optimization procedure is a scaffold porosity distribution which maximizes a given objective function, e.g., the stiffness of the scaffold and regenerated bone system over the entire regeneration time, so that the propensity for mechanical failure is minimized.