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GYROID VS STRUT-LIKE SCAFFOLDS FOR BONE REGENERATION: AN IN SILICO COMPARITIVE ANALYSIS OF HEALING IN LARGE BONE DEFECTS

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Summary: Large bone defect treatment remains a clinical challenge. 3D printed scaffolds might help to overcome this challenge to stimulate regeneration of large bone defects by providing biomechanical cues to guide bone healing (Werner et al., 2017). Different scaffold designs have been analyzed for their healing potential with porosity, pore size, architecture, etc. being influential to the healing outcome (Pobloth et al., 2018). Gyroid scaffold designs have been discussed as a promising concept for their high surface area to volume ratio to enhance cell adhesion (Yoo et al., 2014). However, their regeneration potential remains to be investigated. The aim was to investigate the general potential of gyroid scaffolds to support bone regeneration compared to strut-like scaffold concepts. To allow a parametric comparison, an in silico approach was chosen to investigate the bone regeneration process within gyroid and strut-like scaffolds. The in silico models combined finite element (FE) analysis, to determine the mechanical environment within the scaffolds, and agent-based models (ABM) to characterize biological processes taking place during bone regeneration. Previously, we could demonstrate that such models are able to explain bone regeneration within titanium scaffolds (Perier-Metz et al., 2020). Both, gyroid and strut-like scaffolds had the same overall geometry: 5mm height and 79% porosity. Scaffolds were virtually inserted into a computer model of a large bone defect in a rat femoral osteotomy model, replicating a previously described experimental setup (Wehner et al., 2010). Scaffold pores were initially filled with granulation tissue, while PCL material properties were assigned to the scaffold. Moreover, scaffold pores were assumed to be filled with bone graft material (Perier-Metz et al., 2020). The spatial distribution of the initial mechanical stimuli within the gyroid and strut-like scaffolds were considerably different, despite being under the same overall mechanical loading. Initially, most of the tissue volume within the strut-like scaffold was under mechanical stimuli beneficial for bone formation. The gyroid scaffold resulted in higher initial mechanical stimuli, with relatively large tissue volumes under mechanical signals beneficial for cartilage and fibrous tissue formation. In both scaffolds, bone was predicted to start forming from the top and bottom surfaces and formation slowly progressed towards the center region by intra-membranous ossification. The healing outcome, however, was considerably different between the two scaffolds: while in the strut-like scaffold bony bridging was observed, the gyroid scaffold resulted in void regions within the scaffold core. Our results show that computer model predictions of bone regeneration are influenced by scaffold structure. This is in accordance with experimental studies showing different healing outcomes for different scaffold designs. Computer model predictions showed distinct initial mechanical environments within the scaffold pores in the gyroid versus the strut-like scaffold. In addition, the large curvatures of the gyroid scaffold slowed down the penetration of the cells resulting in slower healing dynamics and reduced bone formation. Future studies will investigate the effect of other scaffold designs and further validate computer models by comparison of model predictions with experimental data.