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GEOMETRY OPTIMIZATION OF REGULAR SCAFFOLDS FOR BONE TISSUE ENGINEERING: A MECHANOBIOLOGICAL APPROACH

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Summary: We propose a mechanobiology-based optimization algorithm to identify the best geometry that regular scaffolds must possess to maximize the formation of bone, thus shortening the healing time. The computational mechano-regulation model of Prendergast and Huiskes was utilized to analyze the scaffolds mechanobiological response. The scaffold domain is modelled as a biphasic poroelastic material and the biophysical stimulus triggering the tissue differentiation process is hypothesized to be a function of the octahedral shear strain and of the interstitial fluid flow. The poroelastic FEM model of scaffolds based on different unit cell geometries was developed and incorporated in a numerical optimization algorithm that iteratively perturbs the scaffold geometry until the optimal one is determined, i.e. the geometry that favors the formation of the largest amounts of bone for the specific load value acting on the scaffold. Namely, the following unit cell geometries were investigated and compared: hexahedron with elliptic and rectangular pores, truncated cuboctahedron, truncated cube, rhombicuboctahedron, rhombic dodecahedron, diamond, hexahedron with spherical pores and FDM-based unit cell. In all these scaffold models, the mesenchymal tissue occupying the scaffold pores was simulated and the biophysical stimulus acting within this tissue when a compression load is exerted on the top scaffold surface was computed. A Python script was generated for each of the above-mentioned geometries that allows parameterizing specific dimensions of the scaffold unit cell. For each hypothesized load value, the objective function was determined, i.e. the ratio between the volume of the elements of the mesenchymal tissue that are predicted to differentiate into mature bone and the volume of all the elements of the entire scaffold model. *Fmincon*, the optimization tool available in Matlab to determine a constrained minimum of a scalar function of several variables, was utilized in the scaffold optimization process. Interestingly, we found that the optimal scaffold geometry is a function of the load acting on it. For very high load values, the scaffold with hexahedral unit cell and elliptic-rectangular pores is preferable to the others. For lower load values, the truncated cube unit cell seems to perform better than the others do. Finally, for high-medium load values, the rhombic dodecahedron unit cell appears preferable. In a context dominated by the so-called Precision medicine, where the therapy becomes a patient-specific procedure, the proposed algorithm appears to be a very promising tool capable of designing smart scaffolds, i.e. scaffolds suited to stimulate the formation of the largest amounts of bone on the specific patient with specific anthropometric features. The algorithm can conveniently support the surgeon in the choice of the best scaffold geometry to be implanted on the patient, that is more capable to bear the load and to transfer it to the adjacent tissues, thus shortening the hospitalization and, in general, the healing times.