MICROSTRUCTURAL DESIGN OPTIMIZATION OF TISSUE SCAFFOLDS: DEGRADATION V.S. REGENERATION – A MECHANOBIOLOGICAL STUDY

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Introduction

As two main processes in tissue scaffolds, matrix degradation weakens the mechanical properties of scaffold, while neo-tissue continuously replaces the mechanical function of matrix material and restores the biological role of original tissue. Thus, they are of great interest to evaluate the performance of tissue-scaffold systems during regenerative process. This paper aims to develop a systematic mathematical framework that explores the evolutions within biodegradable scaffolds and then find out the optimal scaffold microstructures as well as degradation rate subjected to various design criteria.

Methods

To explore the impact of scaffold microstructures on the mechanobiological evolutions of tissue-scaffold systems, different cellular architectures acquired from multi-objective topology optimization, including both stiffness and permeability criteria, are considered [1]. Representative volume element (RVE) is extracted from cellular structures as the design domain, subjected to hydrolysis reaction which is modelled in a discrete fashion by a fundamental stochastic process and an additional autocatalytic effect induced by the local carboxylic acid concentration [2]. To simulate tissue growth such micro-environment, a mechano-regulatory model which characterizes tissue regeneration regulated by external mechanical stimuli is adopted [3].

Results and Discussion

The illustrative examples of cellular tissue scaffolds demonstrate the applicability of proposed models. For the scaffold degradation, on the one hand, it is found that diffusive transport plays a critical role in determining the degradation pathway, whilst autocatalysis makes the degradation size dependent, as shown in Fig. 1 [2]. Such size-dependence signifies great importance of optimizing the architecture (including wall thickness and connectivity) of scaffold matrix so as to achieve optimal degradation rate and pH distribution, which provide better mechanical and biochemical environment during tissue regeneration. On the other hand, it is found that the microstructural design of scaffold has a significant impact on tissue regeneration outcome. The stiffness and permeability of RVE design would significantly alter the scaffold micro-environment, thus greatly change the mechano-regulatory tissue regeneration process. By using the homogenization method, the evolving properties of tissue-scaffold systems during scaffold degradation and tissue regeneration are examined to reveal the relative importance of different design criteria adopted [1]. Finally, the optimal degradation rate of scaffold matrix is acquired by evaluating the effective properties of tissue-scaffold systems subjected to both material biodegradation and tissue ingrowth. This study models such an interactive process of scaffold degradation and tissue growth, thereby providing new insights into design of biodegradable scaffold micro-architecture for tissue engineering.

References