Topology Optimization of Tissue Scaffolds for Biotransport Criteria

Che-Cheng Chang[1], Shiwei Zhou[2], Wei Li[1], Qing Li[1]

[1]School of Aerospace, Mechanical and Mechatronic Engineering, The University of Sydney,
Email: qing.li@sydney.edu.au
[2]School of Civil, Environmental & Chemical Engineering, RMIT University, Melbourne, Australia

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Design and control of microstructure signifies a major challenge in the development of porous tissue scaffolds. Past studies have established a range of porosity requirements for cell survival and proliferation [1]. Numerous biofabrication techniques have been developed to date and employed to produce the required scaffold structures, 3D printing in particularly is one of such techniques widely used for such purpose [2]. In the recent years, topology optimization methods are also applied to this field of research in an effort to determine the best possible microstructures with desirable stiffness and diffusivity/permeability [3, 4]. However, the concept of an ideal tissue scaffold has yet been fully realized, partly because the model quality of common topology optimization methods do not meet the manufacturing requirements, and partly due to the technical limitations in current fabrication techniques to accurately build the desirable microscopic details.

To resolve design realization issue, this study develops a topology optimization method using isosurface modeling technique which allows determining a clearly defined optimal microstructure for biofabrication purpose (e.g. direct 3D-printable output). This method creates computational models with an implicitly defined level set and an explicitly defined isosurface, on which the simulation and design optimization are performed in a more boundary accurate way. The models are optimized using the level set representation to maximize the effective material properties. A range of optimal microstructures with various combinations of effective diffusivity and bulk modulus have been thereafter defined in isosurface form. A smooth Pareto front is also generated. The results show that both the maximum diffusivity model and the maximum bulk modulus model cannot be physically fabricated due to phase discontinuity, otherwise all intermediate models may be considered feasible candidates. With the distinct definition of the surface boundary, this metho is found to be able to better clarify the geometric features of the optimal microstructures and cleared some speculations raised by the past density based topology optimization studies. In addition, the isosurface models and solutions are generated in a triangulated form equivalent to the stereolythography format, conforming to the rapid prototype standard, making the direct exportation to the 3D printable format possible without the need of further processing or human interpretation. The proposed technique is therefore recommended for the design optimization of products such as porous tissue scaffolds that require 3D printing and rapid prototyping.

References

[1] S. Rajagopalan and R.A. Robb, Schwarz meets Schwann: Design and fabrication of biomorphic and durataxic tissue engineering scaffolds, *Medical Image Analysis*, 10(5), 693-712, 2006.

[2] F.P.W. Melchels, B. Tonnarelli, A.L. Olivares, I. Martin, D. Lacroix, J. Feijen, D.J. Wendt and D.W. Grijpma, The influence of the scaffold design on the distribution of adhering cells after perfusion cell seeding, *Biomaterials*, 32(11), 2878-2884, 2011.

[3] Y.H. Chen, S.W. Zhou and Q. Li, Computational design for multifunctional microstructural composites, *International Journal of Modern Physics B*, 23(6-7), 1345-1351, 2009.

[4] Y. Chen, S. Zhou, J. Cadman and Q. Li, Design of cellular porous biomaterials for wall shear stress criterion, *Biotechnology and Bioengineering*, 107(4), 737-746, 2010.