CALIFORNIA STATE SCIENCE FAIR
2012 PROJECT SUMMARY

Name(s)

Namrata R. Balasingam

Project Number

S1803

Project Title

Murray's Principle of Minimum Work and the Biomimetic Design of Efficient Microfluidic Networks for Tissue Engineering

Abstract

Objectives/Goals

The loss of organs due to disease or injury is a major medical problem, and often this problem can be corrected using organ transplantations. Since there is a chronic shortage of suitable organ donors, tissue engineering is being researched as an alternative source of transplantable organs. One major challenge facing this rapidly growing field is the optimal design of artificial vessels that can efficiently convey nutrients and waste across growing pieces of tissue. These artificial vessel systems consist of branching networks of microfluidic channels, whose dimensions vary from tens, to hundreds of micrometers. There is a close resemblance between these artificial constructs and the branching structure of blood vessels in mammals. This has prompted some researchers to propose that Murray's Law, which governs the bifurcation geometry of vessels in the mammalian circulatory system, be applied to the design of artificial vasculature.

Murray's Law predicts that flow rate through a bifurcating network is maximized when the diameters of the daughter vessels taper down from that of the parent vessel by the cube-root-of-two. This law applies only to vessels with circular cross-sections. Our objective is to generalize this result to realistic rectangular channel cross-sections that distinguish artificially constructed vessels from naturally occurring vessels that have circular cross-sections.

Methods/Materials

In my work, I have used the correspondence between Ohm's Law for current flow, and the Hagen-Poiseuille Law for fluid flow to derive formulas for the overall conductance of branching fluid-conveying networks. I wrote a small program that swept the geometric factors over a range of values, and looked for peaks in the conductance.

Results

There were three key findings in my work: (1) when the rectangular channels are strictly square, the tapering rules are exactly the same as those predicted by Murray for circular channels, (2) for more general rectangular networks I showed that the taper factor that maximizes the hydraulic conductance of a bifurcation is a function of the aspect ratio of the parent channel, and (3) for higher-order networks, I showed that the conductance is a sharply peaked function of the taper factor.

Conclusions/Discussion

I generalized Murray's Principle which applies to bifurcating channel networks of circular cross-section to artificial rectangular channel networks.

Summary Statement

I showed that the conductance of a microfluidic network of a given volume can be maximized by the proper selection of geometric scale factors.

Help Received

I would like to thank my advisors Dr. Dipu Pramanik, and Mr. Ronald Nicoletti for their valuable advice on this project. I would also like to thank my dad Dr. Pratheep Balasingam, and my mom for their support, and encouragement.