Replicating Natural Environments: Soil-inspired Microfluidic Architectures

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The development of microbial communities and their interactions with neighboring organisms is strongly dependent on the chemical and physical composition of their local environment. Studies that examine the behavior and function of these communities in the highly ordered and deterministic architectures conventionally used in the field of bio-microfluidics, can provide valuable insights into microbial physiology and community development. However, in order to fully understand the factors that drive emergent behaviors of microbial communities within their native environment, fluidic architectures that systematically retain the heterogeneity of natural physical environments, such as natural soil, are required. Within soil, nutrient availability, chemical communication, motion, and the spatial distribution of microbes is dictated by the structure and hydrodynamics of their environment. Realistic microfluidic architectures are therefore needed to identify and replicate emergent phenomena in these communities.

Here, a method for developing such microfluidic soil architectures from the statistics of natural sand samples is demonstrated. Using previously collected data on natural particle shape, size, and porosity,[1] and a published granular media generator[2], we have produced microfluidic replicates of sand samples from four distinct geographical locations. The simulated porous media (Figure 1a) were vectorized and converted to computer-aided designs (Figure 1c) to be duplicated through standard photolithography. The designs were copied to a silicon wafer using a 15 μm thick SU-8 photoresist and poly-dimethylsiloxane (PDMS) molds were used for high-throughput experimentation (Figure 1e). Deep reactive ion etching was also tested, ultimately increasing the lifetime of the silicon masters and potentially improving the quality of pattern transfer. The fidelity of the fabrication process was measured by comparing the resulting PDMS channel porosity to the simulated media (Figure 1d).

To further characterize the hydrodynamic flow in these systems, COMSOL Multiphysics® was employed to simulate the velocity profiles in each of the porous media geometries (Figure 1b). Flow characteristics are being correlated to the granular media's parameters in order to generate prescribed flow patterns in future experiments. The characterization of microfluidic porous media parameters using particle velocimetry, and the impact of soil architecture on microbe accumulation and biofilm initiation in these microfluidic platforms will be discussed (Figure 1f).

<u>**References**</u>

1. Das, Nivedita (2007) “Modeling three-dimensional shape of sand grains using Discrete Element Method” *Graduate Dissertation, University of South Florida.*

2. Mollon, G., & Zhao, J. (2012). “Fourier-Voronoi-based generation of realistic samples for discrete modelling of granular materials.” *Granular Matter*, *14*(5), 621–638

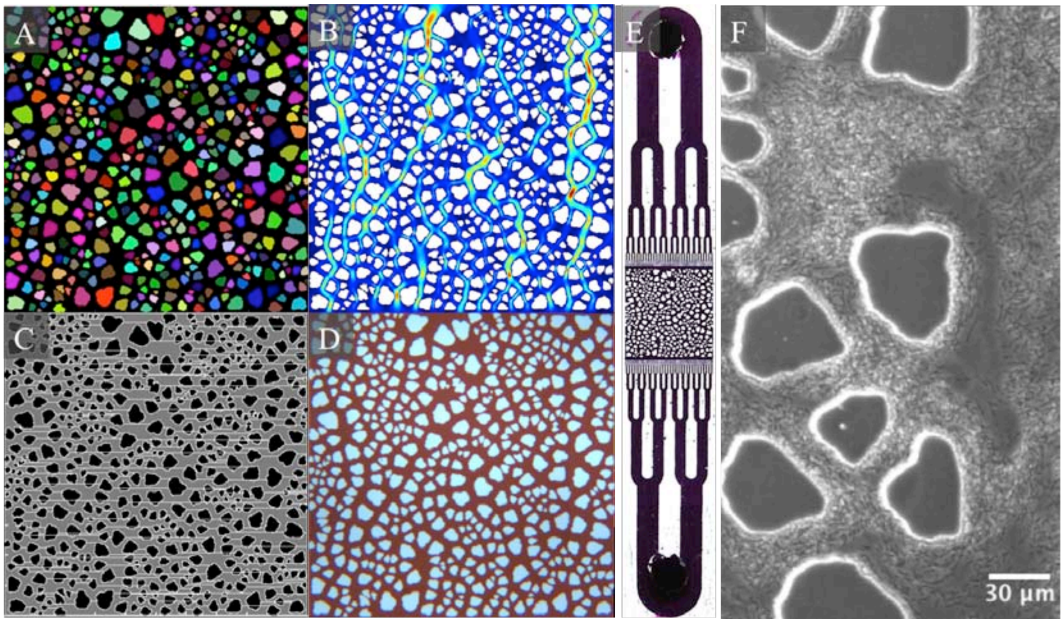

Figure 1: (a) Example of the simulated porous media with a porosity of 59.3%. (b) COMSOL Multiphysics simulation of the same media, showing the velocity profile for a uniform flowrate. (c) A computer-aided design file is created from the simulated porous media using a vectorization procedure. (d) The resulting microfluidic soil analog is filled with dye for visualization. Porosity in this device is 60.9%, illustrating that 1.6% of solid was lost in the fabrication process. (e) The entire microfluidic device is shown. Bifurcating ports distribute the inlet flow uniformly. (f) Phase contrast image (20x) showing the accumulation of Pantoea spp. YR343 in the microfluidic soil after 1 hour.