Editorial

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Mesoporous Biomaterials – multifunctional materials for future medical therapies and bioanalysis

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Nanoscience and nanotechnology – the ability to not only fabricate precisely at the nanoscale, but also fully characterize and understand behaviour at these dimensions, is now having some profound influences on medicine. Richard Feynman is widely credited with prompting this era with his challenging 1959 lecture *"There's Plenty of Room at the Bottom"*.

When we look at how biomaterials have evolved over many centuries (Figure 1), they have moved from convenience (wooden replacement teeth) to resilience (stainless steel hip implants) to temporary forms (biodegradable implants and tissue engineering) that increasingly utilize nanotechnology. The relative number of new solid biomaterials appearing has also gradually declined at the expense of porous or "nanocomposite" ones, as the material approaches to assisting healing have become more and more biomimetic. Indeed, living organisms rely on pores to function to such an extent that our own bodies are highly porous over widely varying length scales. Blood perfusion around the body is based on conduits of hugely different diameters (arteries, arterioles, capillaries, venules and veins). Our bone remodelling relies on osteoclasts adapting its macro- and mesoporosity in-vivo and sensing the local stress fields via fluid flow. At the tissue level, our skin relies on macropores for homeostasis. At the individual cell level we rely on membrane proteins that create micropores for moving molecules in and out.

So, what pore sizes are needed for biomaterials? Biomaterial scaffolds for tissue engineering are a clear example where high levels of macroporosity and very large pores (pore diameters normally in excess of 100 microns) are essential for cellular infiltration, but additional mesoporosity can be very beneficial. Indeed, the so-called "hierarchical porosity" of very broad pore size range is increasingly used here. Biomaterials for immunoisolation on the other hand require tightly controlled mesoporosity

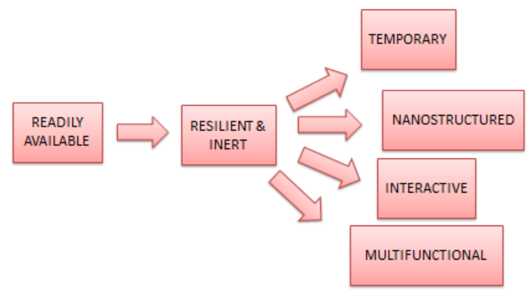

Figure 1: Biomaterial evolution: more interactive, multifunctional, nanostructured and porous.

alone to allow transport of small biomolecules, but act as a barrier to immune cells and antibodies.

A range of mesoporous biomaterials across most material classes are now under evaluation (Figure 2). Indeed, mesopores of diameters in the range 2 – 50 nm are of particular importance in biomaterial design for a number of reasons.

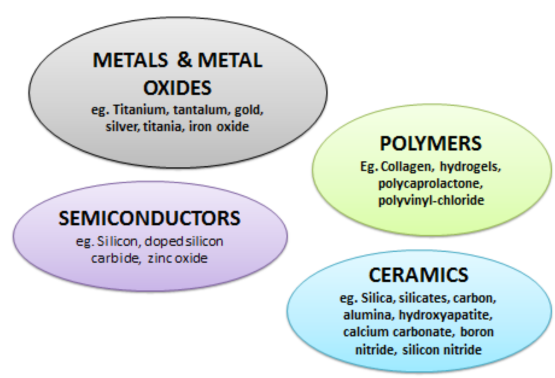

Figure 2: Mesoporous biomaterials under evaluation.

With some materials, the semiconductor silicon being a notable example, really dramatic effects on properties can result from such nanostructuring. Mesoporous silicon is medically biodegradable whilst macroscale solid silicon is not. For metals and ceramics in particular, mechanical properties become highly tunable with mesoporosity. This is particularly useful in orthopaedics where one wants to match stiffness with that of bone to minimize “stress shielding”. Mesoporous polymers have been realized to mimic the quasi-ordered reticular structure of the extracellular matrix, and can exhibit reversible porosity. However, perhaps the broadest attribute of mesoporosity for medical therapy is that any implanted material can then become a “carrier” for at least one other therapeutically useful substance; a drug, a radioisotope, a nutrient, a phosphor, a nanoparticle, etc. With mesopores there is also a much broader range of substances that can be loaded compared to micropores of diameter below 2 nm. Optimized design of mesoporosity can realize nanocomposite structures with a medical payload whose release could be targeted to disease sites and rate of release can be controlled. For mesoporous aerogels, aerocrystals and metal oxide frameworks’, which have very high porosities (pore volumes), the drug payload has the potential to be very high.

For biomedical sensing, a mesoporous substrate offers a huge improvement mainly due to its surface area which can easily be modified to provide different functionality, whilst having pore sizes that present less hindered transport of analytes compared to micropores, and thus, giving acceptable response times and increasing the selectivity and the sensitivity of the detection.

For biomedical analysis, the combination of huge surface areas, and filtration capabilities of mesoporous biomaterials offer a means to both selectively capture, and concentrate target molecules from complex biological fluids and then protect them from the external environment prior to analysis. Mesoporous chip and particle-based substrates have already received much development for applications like proteomics.

From more than one perspective it would thus appear that Mesoporous Biomaterials is indeed an emerging exciting field where “*There’s Plenty of Room Inside*”.

Leigh Canham
Editor-in-Chief

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Journal Editor

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Associate Editor