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Bioinspired Strategies for Novel Bone Scaffolds

Abstract: The repair and replacement of skeletal tissue by synthetic materials remains one of the greatest challenges in health care today. Although metallic orthopedic and dental implants enjoy widespread use and success in modern clinical practice, they remain poor substitutes for the tissues they are intended to replace. Humans are biological — not metallic. The idea of using synthetic composite materials as permanent replacements for bone generated much excitement 30–40 years ago, but their promise has been largely unfulfilled because of significant challenges related to fabrication, performance, and cost. Rather than lasting 15 or more years as designed, implants have recently been failing at astonishingly high rates. Half of all hip replacements will have to be removed after only six years. A recent paper on implants [1] suggests that newer designs for artificial hips and knees did not perform any better than older, less expensive technologies. In this context, an unprecedented opportunity exists for the materials sciences community to develop new implant materials and provide novel solutions for implant designs. Practical solutions to this problem depend critically upon basic science, and the field demands a fresh, truly multidisciplinary approach. How can such major advances in implant materials be realized?

Nature is very adept at creating strong and tough hybrid structures, such as seashells, wood, bone, and teeth, which have far superior mechanical properties than their separate constituent parts. Nature-inspired designs are part of the field called biomimetics, or biomimicry, which is devoted to producing synthetic materials that imitate the architecture of biological materials. We pioneered the use of the intricate microstructure of ice as a template for the fabrication of complex hierarchical inorganic/organic composites [2]. This technique, known as freeze casting, allows the manipulation of the architecture of hybrid materials at multiple length scales with an unprecedented degree of control. The approach is based on replicating natural structures in synthetic implant materials. As a proof of concept, we have recently demonstrated how nature's design concepts can be applied to bulk hybrid materials comprised of two conventional, low-toughness compounds: hydroxyapatite and aluminum oxide with PMMA. Using freeze casting, we have created ice-templated hybrid structures with exceptional toughness that are

over 300 times higher (in energy terms) than their ceramic and polymer constituents. Our goal is to translate this approach to implant designs that would be significant improvements over existing devices.

1. Anand, R., et al., What Is the Benefit of Introducing New Hip and Knee Prostheses? J Bone Joint Surg Am. 2011. 93 (Supplement 3) (December 21): p. 51-54.
2. Deville, S., et al., Freezing as a path to build complex composites. Science, 2006. 311(5760): p. 515-518.

Bio: Prof. Tomsia obtained his PhD in 1975 from the Institute of Materials Science in Krakow, Poland. After that, he continued his research in California, at the Lawrence Berkeley National Laboratory, where he has worked on the development and characterization of biomaterials, especially for bone repair. His approach to this complex task is to combine new materials development with radically novel design philosophies, producing bioactive scaffolds that are intended to be partially or completely resorbed and replaced by bone from the host - a sequence resembling bone remodeling.