Sensorized Biomimetic Scaffolds: Toward Universal Bionic Interfaces

Participants

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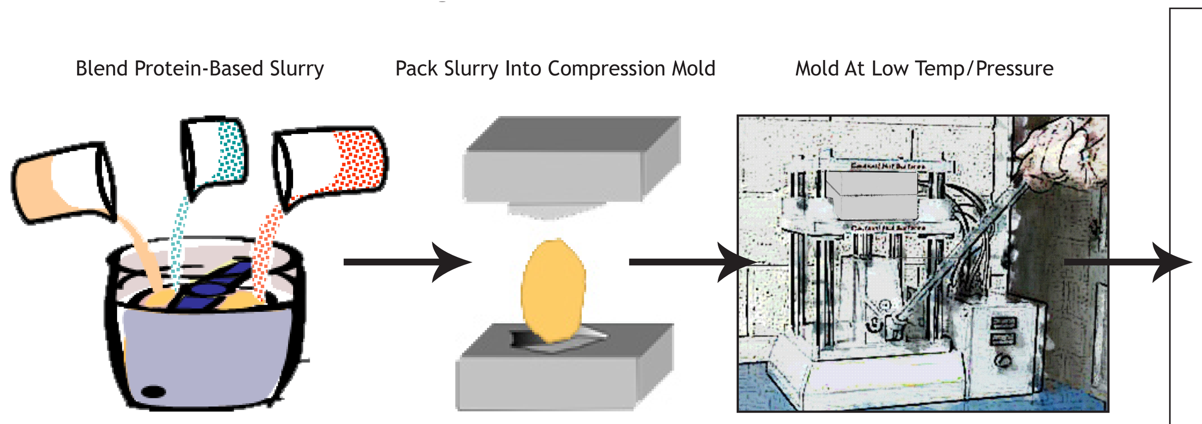
Introduction

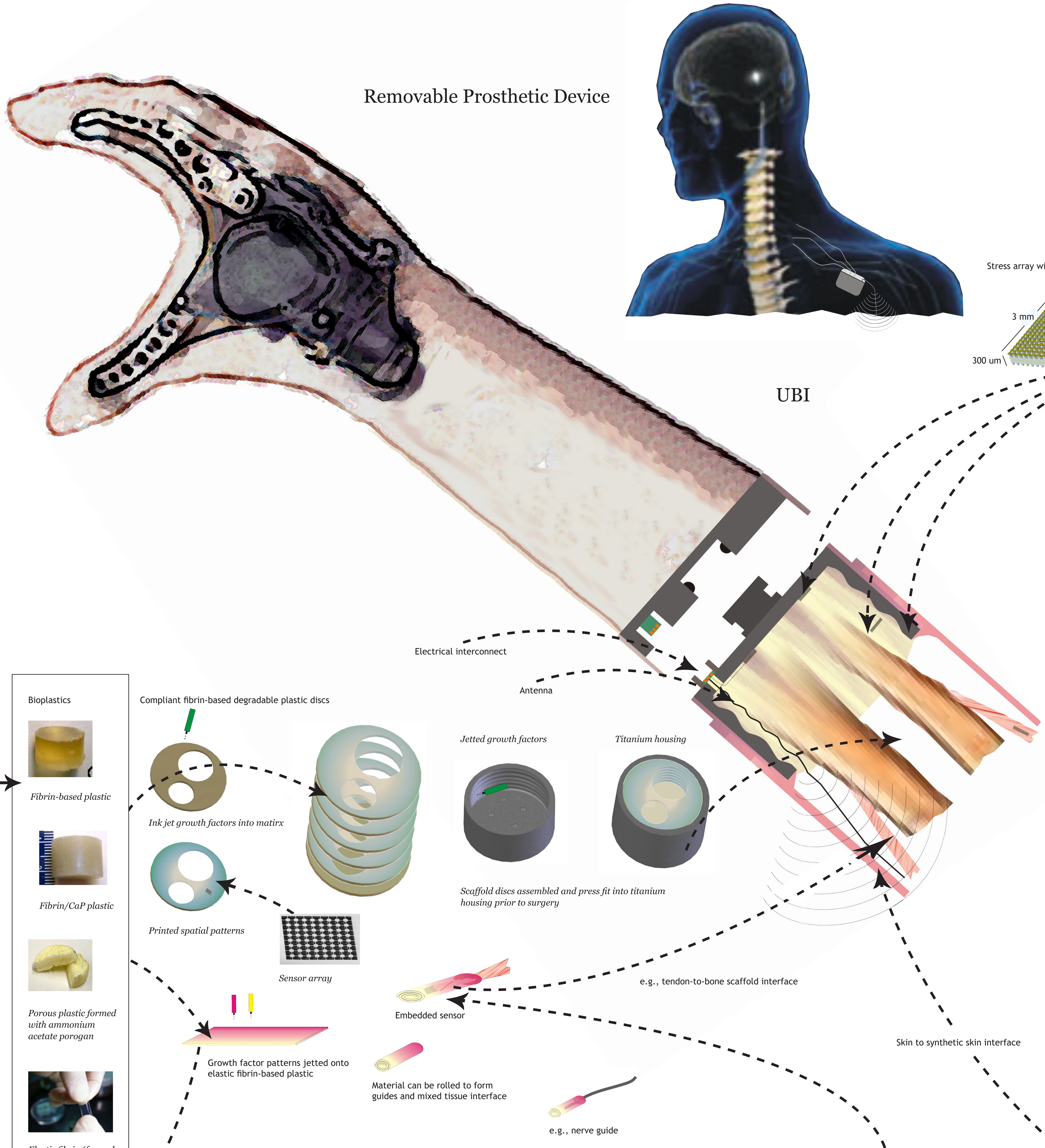
Long term biointegration of prosthetic devices is a goal that heretofore has not been achieved. One envisioned strategy would utilize a permanently implanted device that interfaces prosthetic modules with intact tissues such as bone. This Universal Bionic Interface (UBI) would provide for a stable and comfortable attachment of smart prosthetics to the body and electrical feed-throughs for signal and power interconnections to implanted sensory systems. The UBI inlcudes (i) a bionic stump which inlcudes embedded biomechanical sensors, (ii) RF communication to peripheral nerves, (iii) communication protocols, and (iv) standardized interface from factors.The modules would be controlled using feedback from sensors that measure bioelectrical, biomechanical and biochemical signals. Detachable prosthetic modules would enable interchangeable functionalities, facilitate module repairs when needed, and permit evolving designs to be added, all without the need to surgically reestablish the biointerface. Numerous enabling technologies will need to be developed, tested, and integrated to realize UBIs. We are developing several such technologies that could be applied toward this goal, including: methodologies that could promote osseous and soft tissue integration with UBIs; and, miniature wireless sensor technologies, with a current focus on intraosseous strain gage arrays that could both monitor functional integration in situ over time and ultimately provide biomechanical feedback signals for control.

2. Bioplastics Scaffolds

A complementary technology is our biodegradable protein-based plastic scaffolding, which can be used to interface bone with Ti/ceramic UBI components. These native protein biopolymers can be engineered to have a range of initial biomechanical properties (elastic, to rubbery, to hard). Due to low processing temperatures (<60°C), hormones and other biologicals can be incorporated. Sublimination porogens and nanoparticulate calcium phosphate (CaP) can be included to provide porosity and osteoconductivity, respectively. Biopolymer degradation is in response to cellular proteolytic processes such that degradation occurs in concert with the growth and healing of host tissues. Cross-linkers such as vegetable-based Genipin can be added to further delay degradation. As with other plastics, bioplastics can be post processed by a wide variety of manufacturing techniques including extrusion, molding, and machining.

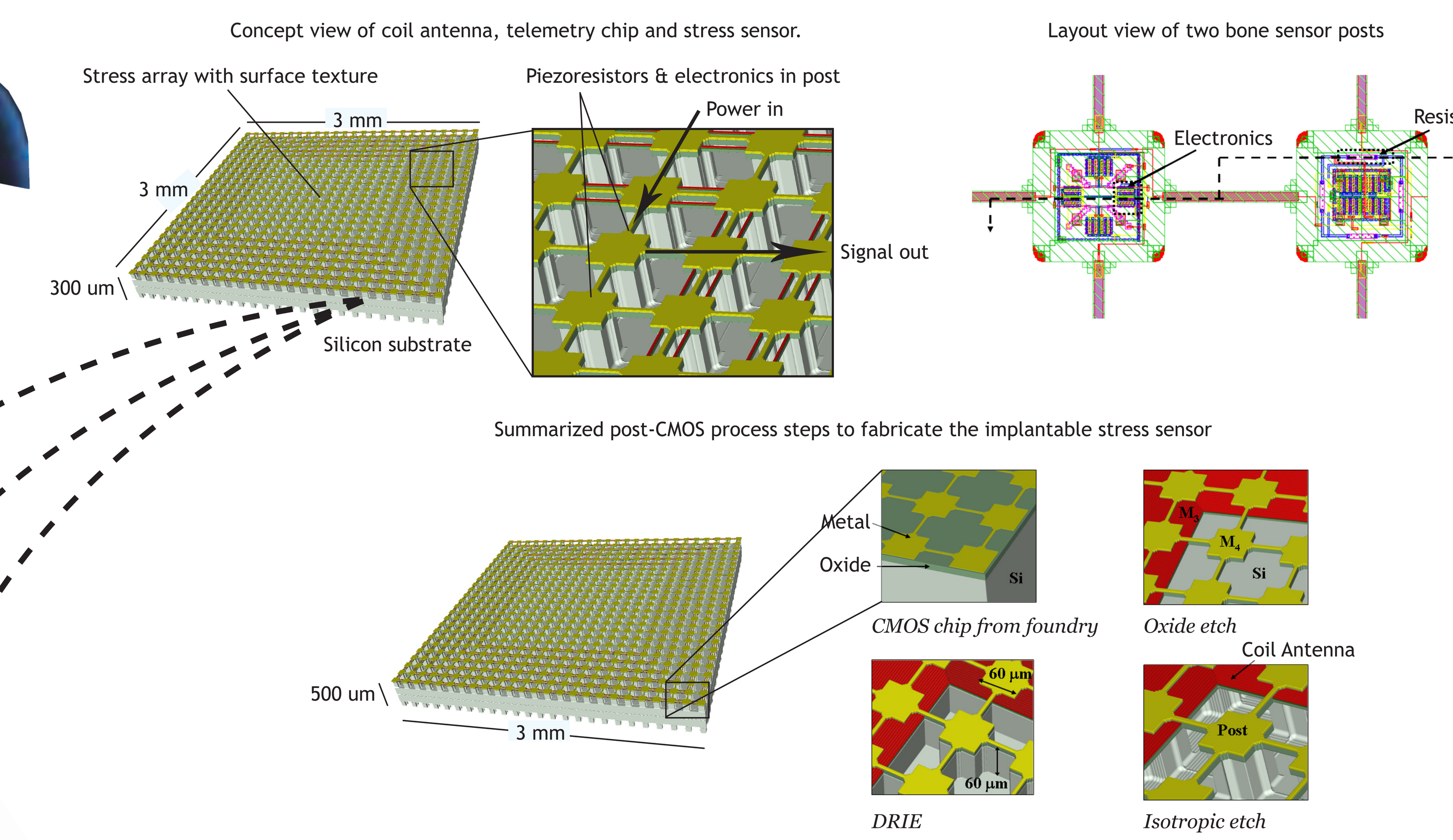


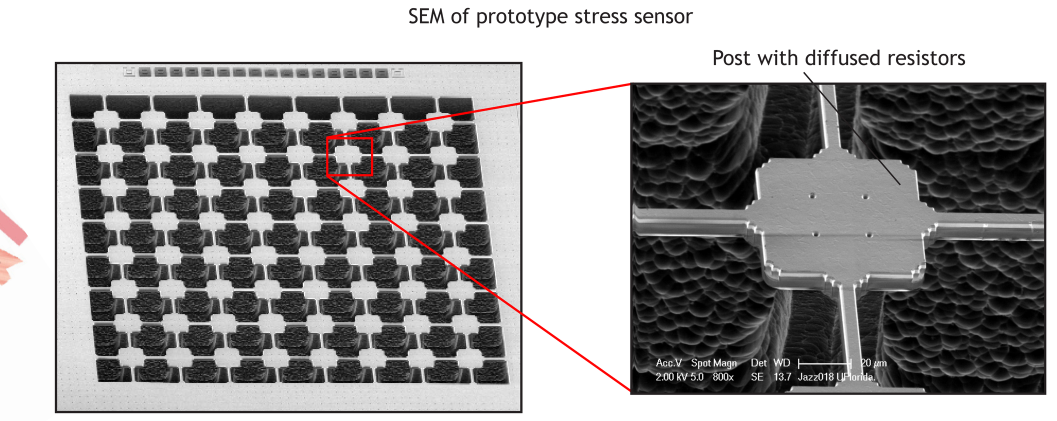
-Growth factors, porogens, cross-linkers, drugs, calcium particulate.
-Glycerin plasticizer.
-Milled protein (eg. fibrin, collagen, ECM)

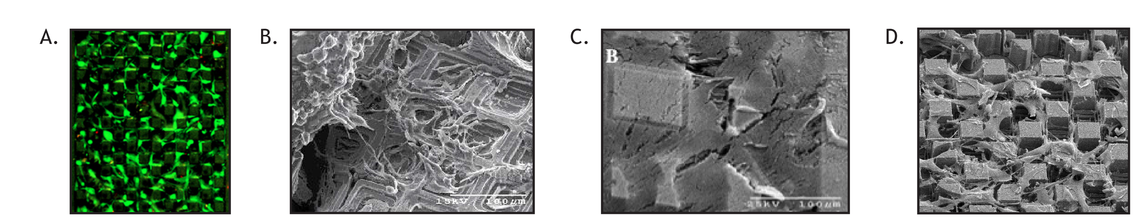


1. Wireless Bone Implantable Sensor

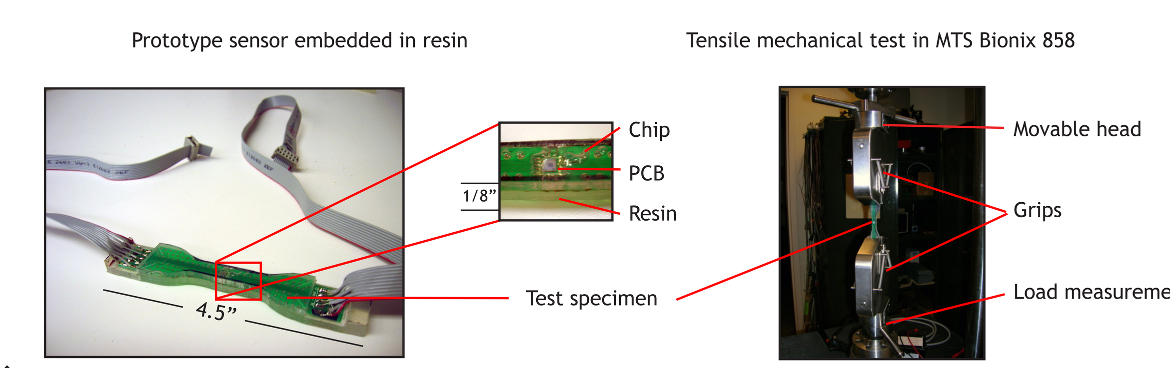
Enabled by our advances in CMOS-MEMS technology, we are also developing an ultra-miniature (3 mm x 3 mm x .3 mm) wireless sensor that can be permanently implanted within tissues to measure biomechanical stresses *in vivo* at a micro scale. This sensor integrates an array of piezoresistive strain gages that produce the raw data needed to extract a stress tensor and a transmission/reception coil and electronics for wireless power and data transmission. Osteointegration of the device, when placed within remodeling bone tissue, is enhanced through a combination of optimized surface topology and a titanium-oxide/bioceramic coating. Such sensors could be deployed within the biopolymer scaffolds of the UBI. Of special interest is the development of base technology for other ultra-miniature RF powered implantable devices. An integral RF-based telemetry system, which would provide for wireless transmission of energy and data to either a base station fixed to the UBI or to an external reader, would eliminate practical problems associated with hard wiring to micro-embedded sensors.





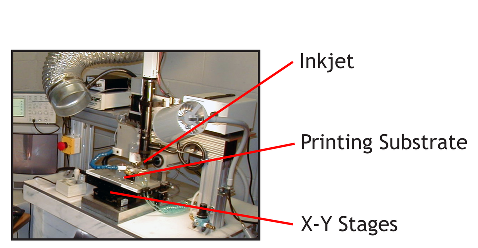


A. Live/Dead fluorescent staining. Green=alive, red=dead. 250 um.
B. SEM characterization of Si sensor with MG-63 cells. 100 um.
C. Si sensor topography underneath layer of hAMSC. 100 um.
D. 400 um.

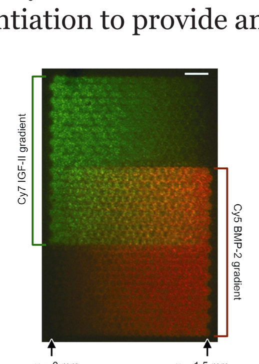


3. Growth factor gradients

To provide persistent spatial hormonal cues to direct tissue in-growth and improve the tissue/implant interface we have developed an inkjet bioprinting technology capable of the manufacture of both 2D and 3 D spatial patterns of immobilized hormones to direct cell behavior. By example, the 2D printing shown here is capable of creating complex, interacting hormonal gradients that can then be shaped (e.g. by stacking or rolling) into 3D spatial patterns. Stacked or rolled layers of compliant bioplastics could be press-fit into a UBI titanium housing, and then surgically prepared bone could be press-fit into the scaffold to create an initial biomechanically stable environment to provide spatial cues to direct host cell ingrowth and differentiation to provide an improved implant/tissue interface.



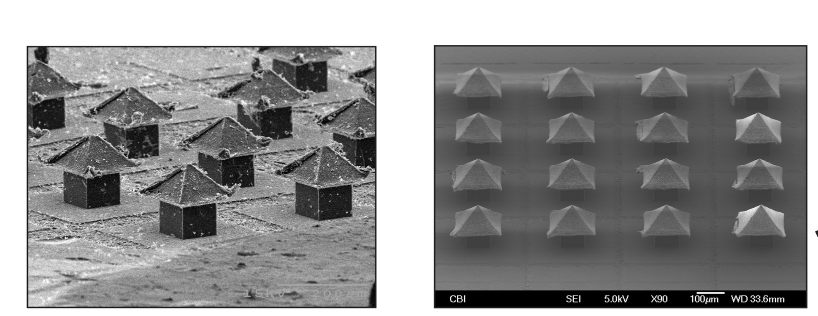
Growth factor patterns jetted onto elastic fibrin-based plastic.



Printed gradient on bioplastic sheet

4. Microbarb fasteners

In addition, microbarb connectors, which we are developing using novel micro-milling techniques to shape our protein-based plastic biopolymers, could be used in conjunction with our elastic biopolymer scaffolds to facilitate reattachment and integration of tendons and bone. The micro-milling can be done for other materials as well.



Fibrin

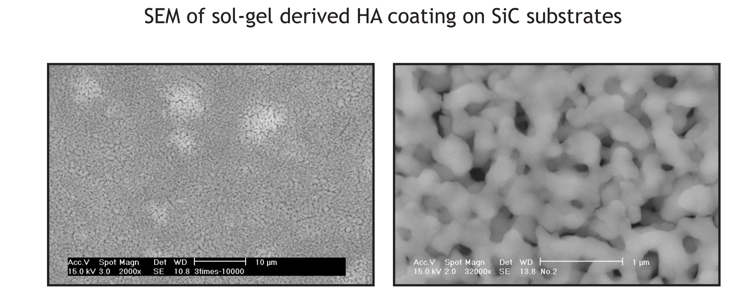
PMMA

Micro-milled, microbarb structures.

5. Ti/ceramics interfaces

Bone integration bone with titanium alloys (e.g. the housing materials for UBIs) is achieved with the use of our novel sol-gel processing methods to coat titanium with controlled morphologies and microstructures of bio-active bioceramics to promote favorable tissue responses.

SEM of sol-gel derived HA coating on SiC substrates



- No cracks on the film.
- Smooth surface.

- Sintered Grain size-100-200nm

A similar approach can be extended to generating HA (Hydroxyapatite) films of controlled porosity and thickness on Ti substrates.