The National Academies Keck Futures Initiative is accepting applications from researchers for "Smart Prosthetics: Exploring Assistive Devices for the Body and Mind

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Sensorized Biomimetic Scaffolds toward Universal Bionic Interfaces

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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 for electrical feed-throughs for signal and power interconnections to implanted sensory systems. 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.

One approach for integrating bone with titanium (e.g. the housing of a UBI) is 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. A complementary technology is our biodegradable protein-based plastic scaffolding, which could be used to interface bone with Ti/ceramic UBI components. These native protein biopolymers, which can be engineered to have a range of initial biomechanical properties (elastic, to rubbery, to hard), degrade in response to cellular proteolytic processes so that degradation occurs in concert with the growth and healing of host tissues. To direct angiogenesis, which is the precursor to osteogenesis, these scaffolds could also be used to deliver 3D spatial patterns of growth factors deposited with ink jet printing onto layers of these materials. Assembled 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 promote osteointegration over fibrous in-growth. 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 elastic biopolymer scaffolds to facilitate reattachment and integration of tendons and bone.

Enabled by our advances in MEMS-CMOS technology, we are also developing an ultra-miniature (3 mm x 3 mm x .5 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 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/biocermic 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.