Developing Bio-inspired Implants to Restore Sight

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Impact

Imagine a world in which damaged parts of the body - an arm, an eye or the brain – can be replaced by electronic implants capable of restoring or even enhancing human performance. The associated improvements in the quality of people’s lives would revolutionize the medical world and produce sweeping changes across society. Nano-biotechnology has the potential to transform this imagined world from science fiction into science fact. For example, over one million people around the globe are diagnosed with retinal diseases each year, inspiring the development of eye implants to restore vision (Figure 1). Over 80,000 Americans have brain implants with the hope of combating conditions such as Parkinson’s disease. Unfortunately, today’s implants are severely limited by the interface between the implant and the body. Our solution is to develop ‘bio-inspired’ implants that mimic the biological systems they communicate with.

![Figure 1: Electronic implants (left) can be inserted into diseased regions of the retina at the back of the eye (right). Analogous to a digital camera, the implant features thousands of ‘pixels’ which convert the incoming light into electrical signals. However, implants face an epic challenge that cameras avoid – they have to pass these signals into the body. Clues from nature are helping us overcome this challenge.](image)

Novelty

Our bodies use neurons for their electrical ‘wiring.’ Neurons connect the retina to the brain, allowing us to see; they connect fingers to the brain, allowing us to feel; they connect regions of the brain, allowing us to think. Neurons look just like miniature trees. Their branches trace out patterns called fractals (Figure 2). By incorporating fractal electronics into the surfaces of our implants, the body will interpret them as neurons rather than as artificial devices. Our research predicts that this will enhance the communication of electrical signals from the implant to the neurons. In contrast, today’s conventional implants are not optimally designed to interact with neurons. Over the past decade, three companies (Second Sight, Retina Implants and Pixium/Optobionics) have implanted devices in approximately 200 patients, but all of these
implants rely on the traditional electronics developed for commercial applications such as digital cameras, cell phones, and computers.

Figure 2: Our bio-inspired electronics (left) replicate the fractal-shaped branches of the neurons (middle). These fractal designs are radically different to conventional circuit designs (right). Each of our fractal trees spans one millionth of a meter with its smallest branches measuring close to one billionth of a meter.

Our bio-inspired electronics hold game-changing consequences for all electronic implants. However, our initial focus is on retinal implants designed to combat diseases such as macular degeneration and retinitis pigmentosa. Their enhanced communication with the retinal neurons has the potential to restore vision sufficiently for people to read text and facial expressions – essential capabilities for performing daily tasks (Figure 3). Our implants also have the potential to allow patients to see in realistic lighting conditions and to see in color. Furthermore, the surgery for our implants will be less obtrusive, reducing surgical costs and patient recovery time.

Figure 3: Simulated images of my dog when viewed using a healthy eye (left image, representing 20/20 vision), using a fractal implant (middle image, representing 20/80 vision), and using a conventional implant (right image, representing 20/550 vision). The right image demonstrates the best vision ever achieved with a conventional implant and this was achieved with just one patient. This level of vision is worse than legal blindness (20/200 vision). In contrast, fractal implants will capture the essence of the object being viewed.
**Time line of recent successes**

2014. My fractal implant proposal beat 950 competing ideas to win an InnoCentive Prize. This prize resulted in two visits to the White House (http://research.uoregon.edu/news/faculty-stories/uo-research-goes-washington).


2016. The project underwent a ‘Lens of the Market’ assessment. This 6-month study concluded that our technology could restore vision to more than 1 million people with dry macular degeneration and 21,000 people with retinitis pigmentosa. Professor Tim Stout at Baylor College of Medicine was one of the eye specialists consulted. Based on their potential to deliver 20/80 vision, he described the fractal implant as the only viable technology for widespread use. He concluded that our “retinal implants will be a necessary disease agnostic approach” for restoring vision.

2016-18. The WM Keck Foundation awarded US$900,000 to assemble and fund the research of a unique, interdisciplinary team of UO professors and their students (Figure 4) (http://www.oregonquarterly.com/regenerating-vision).

2017. Building on our two earlier review articles, in July we published our first results from the Keck project in the journal Nature. Since then we have submitted 2 further papers for publication and 2 more are in preparation. (https://blogs.uoregon.edu/richardtaylor/files/2017/08/Watterson_et_al-2017-Scientific_Reports-vp9swd.pdf).

Figure 4: Top: the team of UO professors consists of Richard Taylor (Physics), Benjamin Aleman (Physics), Miriam Deutsch (Physics), Darren Johnson (Chemistry) and Cris Niell (Biology). Bottom: the team features 7-8 graduate students from biology, chemistry, neuroscience and physics. International collaborators include Professor Simon Brown (University of Canterbury, New Zealand) and Professor Maithe Perez (Lund University, Sweden).
Three stages to success

Our program consists of three overlapping phases:

**Computer modeling (completed):**
Our published simulations demonstrate that the fractal design maximizes both the light entering the implant and the electrical signal generated by the implant. As a result, the fractal implant passes its signal to all of the neighboring neurons while the equivalent conventional implant passes its signal to less than 10% of the neurons, resulting in a significant degradation of vision (Figure 5, left).

**In vitro experiments (in progress):**
We have measured three-dimensional images of neurons in order to build implants that replicate their precise shapes (Figure 5, middle). Current experiments involve inserting our implants into cultures of retinal neurons and imaging the neurons as they attach to the implants (Figure 5, right). These experiments demonstrate that neurons attach more readily to our fractal designs than to conventional designs. This intimate physical connection will enhance the transfer of signals from the implant to the neurons. Over the next year, we will confirm this superior operation by imaging neurons which fluoresce when they receive the implant’s signal.

**In vivo experiments (to commence in 2019 if funded):**
We are planning to extend our studies to living systems – initially mice and then humans. This will involve a collaboration with the Casey Eye Institute at the Oregon Health and Science University (Portland). For the mice studies, electrical sensors will be inserted downstream in the brain to confirm that the retinal implant is successfully passing its signals to the neurons.

Figure 5: Computer simulations (left image) quantify the successful transfer of signals from the implant to the neurons. Three-dimensional images of neurons (middle image) allow us to build implants that match their fractal shapes. A scanning electron microscope image shows a retinal neuron (purple) adhering to the textured surface of our implant (right image).