Retinal Prosthetic Systems for Treatment of Blindness

James D. Weiland, PhD
University of Southern California
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Neurological Disorders

• The human nervous system, when damaged, does not heal well, if at all

• Stroke, Cognitive Impairment, Blindness, Deafness, Chronic Pain, Parkinson’s all are significant, disabling diseases affecting 100’s of millions of people worldwide, costing billions of dollars, and immeasurable misery

• Implantable neural stimulators have successfully treated some of these conditions
Overview

• What is a nerve and how do we electrically connect to a nerve to control activity?
• Current clinical systems for neural disorders
• Retinal Prosthetic Systems
  – Brief history of electrical stimulation for blindness
  – Current clinical prototypes
  – Future of retinal prostheses
Nerve Anatomy and Physiology

• Common features
  – Dendrites, soma, axon

• Synaptic connection to other nerves

• Cell membrane
  – Electrical potential
  – Variable membrane conductance used for signal propagation
Electric fields applied by microelectrode can activate nerve cells

Electrodes are made of
- flexible or rigid substrate
- conducting material (noble metal, conducting polymer, carbon nanotubes)
Cochlear Implants

• Today’s implants stimulate the cochlea at up to 32 locations, but usually use fewer (4-8)
• Best subjects can talk on the telephone (i.e. no lip reading)
Deep Brain Stimulation

• Thalamic stimulation to treat movement disorders (dystonia, chorea, tremor), approved single side 1997, double sided 2002
• Remarkable results, simple device
Human Visual System and Retinal Blindness

- Retina is a light sensitive neural network
- Diseases such as Retinitis Pigmentosa (RP) and Age-related Macular Degeneration (AMD) primarily affect the photoreceptors, are both presently incurable, and render 100,000s blind each year
- Implants have been tested in visual cortex, optic nerve, and retina

Retinal Prosthesis
Systems Level Description

• External camera/image processor detects image
• Telemetry link between external and implanted unit
• Implanted unit recovers power and data
• Implanted unit applies commanded stimulus pattern to the retina via a microelectrode array
LeRoy’s electrical stimulation of a blind person - 1755

- Brass wire wound around the head
- Return electrode attached to right leg
- Charge stored in primitive capacitor (Leyden jar), then discharged through the head
- Blind subject saw a "flame rapidly descending"

Early Implants
Retinal Implant Surgery
Retinal Prosthesis Clinical Trials

Argus II - Second Sight  Alpha IMS - Retina Implant
Mobility Testing
Letter Reading
Summary of Clinical Trials

• Devices appear to be well tolerated by the eye, with only minimal adverse events

• Second Sight and Retina Implant have similar functional results
  – Best subjects are reading letters
  – Visual acuity: RI 20/1000, SSMP 20/1200

• How can we improve results
  – Make current device more effective
  – Make the implant higher resolution
Smart Image Processing

- Use existing video stream to provide more information
- Saliency Algorithm (Itti, et al)
  - Based on primate visual system
  - Highlights “salient” objects based on color, orientation, intensity
  - Top down information improves performance of algorithm

Dr. Neha Parikh, Dr. Laurent Itti

Simulated Artificial Vision
Smart Image Processing

- Mobility and orientation are difficult for blind
- Use computer vision to identify local map and define clear path
- Can work in conjunction with wireless mapping databases
- Possible for use as wearable system for low-vision in general

Dr. Vivek Pradeep, Dr. Gerard Medioni
Simulation of High Resolution Artificial Vision
Needs for High-Resolution Retinal Prosthesis

• Technical
  – Hermetic packaging
  – Dense electronics
  – Smart image processing

• Biological
  – Understanding effects of blindness on the brain
  – Selective stimulation
    • Closer contact between electrode and retina
    • Optogenetic stimulation
Selective Stimulation
Getting Electrodes Closer to Cells

- 18 morphologically different retinal ganglion cell types in primate retina
- With large surface electrodes, simultaneous stimulation of “on” cells and “off” cells
- Penetrating electrodes may allow more selective stimulation

Palanker 2005
Alternative to electrical stimulation

How the ChR2 approach Works

Photoreceptor Cells

Bipolar Cells

Amacrine Cells

Ganglion Cells

Photons

Courtesy of Cyrus Armen
Neural responses generated by ChR2

Threshold is 4 orders of magnitude above cone threshold (bad result, needs to be more sensitive to light)

Courtesy Alan Horsager
Summary

• Clinical trials show some promise
• Technology improvements needed in every area for high-resolution implant
• Strategies needed for optimizing the implantees visual task performance
• How much benefit is enough to change clinical practice?
  – Psychological vs. mobility vs. detailed form perception
Retinal Prosthesis Team Members

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Senior Investigators
Mark Humayun, James Weiland, Wentai Liu, David Hinton, Yu-Chong Tai, Mark Thompson, Armand Tanguay, Norberto Grywacz, Ellis Meng, Elias Greenbaum, Biju Thomas, Lindy Yow, Gerald Chader, Robert Greenberg, Andrea Hodge, Malancha Gupta

Students
Devyani Nanduri, Alice Cho, Tim Nayar, Artin Petrossians, Sam Lee, Andrew Weitz, Samantha Cunningham, Navya Davaluri, Aminat Adebiyi, Nii Mante, Steven Walston, Karthik Murali, Boshuo Wang

Institutions
University of Southern California, Doheny Eye Institute, Cal Tech, UC Santa Cruz, North Carolina State University, Argonne National Lab, Oak Ridge National Lab, Los Alamos National Lab, Sandia National Lab, Lawrence Livermore National Lab, Second Sight Medical Products, Inc., Premitec, Inc., Western Blind Research Center

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