Evaluation of electrical stimulation strategies for selective activation of neurons by a retinal prosthesis

A retinal prosthesis, or the bionic eye, is a promising treatment for the restoration of vision in patients with retinitis pigmentosa and potentially in the future for age-related macular degeneration. Retinal neuroprostheses aim to restore patterned vision to those with vision loss by electrically stimulating the remaining neurons in the degenerate retina. Human trials have demonstrated the ability of these devices to elicit visual percepts or so-called phosphenes. However, the phosphenes evoked by all implants tested to date have remained rudimentary. Human subjects reported the evoked percept, particularly in the low-electrode-count implants, to resemble blobs, streaks, or other, more complex patterns. The device utilises an array of fine electrodes implanted in patient's eyes to deliver electrical pulses to activate the surviving cells in the retina, in particular the retinal ganglion cells which transmit impulses encoding visual information to the brain.

In order for the artificial electrical stimulation delivered by the so-called bionic eye to reproduce physiological vision, the stimulation strategies of these devices have to be programmed to mimic the natural retina in their ability to selectively target neurons. This can be achieved by arrangement of stimulating electrodes or configuring the pattern of electrical pulses delivered by each electrode, areas which our group have been actively researching and developing over the last 15 years.

Our project has used a combination of experimental, imaging and computational modelling to elucidate the mechanisms of selective neuronal recruitment of distinct retinal pathways by high frequency stimulation and thence optimise the stimulation strategies delivered by retinal prosthesis.

In laboratory experiments, retinal tissue preparations were stained for ganglion cells and high resolution 3D geometrical representations of these cells were reconstructed. Fine glass microelectrodes, about a hundredth the size of a single hair were used to record retinal ganglion cell impulses- the building blocks of visual information- in response to artificial electrical stimulation. The neuronal cells shapes and functional responses were captured into a computational model of the retina, which allowed more in-depth analysis of responses.

By adopting this multidisciplinary approach, we were able to show that high frequency stimulation could be used to preferentially activate two retinal cell populations (ON and OFF) each specialising in transmitting distinct visual information to the brain.

Significantly for the bionic eye, this preferential activation works for a range of stimulating electrode sizes and locations meaning it could be employed in a wide range of retinal prosthesis under development around the world.

In addition, a three dimensional computation model of our suprachoroidal retinal prosthesis embedded into a human eye was developed, as a realistic virtual simulation tool to study the patterns of electrical pulses from artificial stimulation on the retina and speedup the design and development of future devices.

Important progress has been made over the last 15 years in the design, development and testing of retinal prostheses, by groups throughout the world and specifically by our team. Given the encouraging initial results in human trials, and indeed, the recent FDA approval of such an implant, it is highly probable that retinal prostheses will be the first widely-adopted therapeutic option for restoring sight to those blinded by neurodegenerative diseases. There is, however, urgency for further research, design and development of improved stimulation strategies for retinal prostheses, in order to progress beyond the simple vision afforded by current devices. This project directly addresses these issues, to provide more targeted activation of neurons, and hence better device-to-neuron integration.

Our results favour a new approach to retinal neurostimulation that will allow targeted neural recruitment. While contributing directly to our knowledge of neural activation in general and retinal neurophysiology specifically, our work will also be a critical enabler of improved vision processing and stimulation strategies in future generations of bionic eye.

We have received a $100k grant from Perpetual Trustees and have recently applied for a four year NHMRC grant to further the work performed in this Retina Australia grant. We sincerely thank the Retina Australia Foundation for their amazing work in progressing targeted research and development in this area for the benefit of those with profound vision loss.