Living Electrodes for Implantable Bionics

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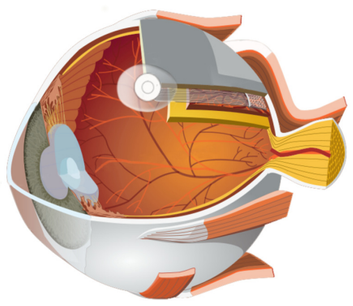
Research Theme: Fundamental and Enabling Research

Background and Motivation

- The bionic eye is an implant developed by Bionic Vision Australia which requires over 1000 electrodes to be inserted into the retina.
- These electrodes form the interface between the body and device, permitting the passage of charge.
- These high density arrays require smaller electrodes than current platinum (Pt) technology safely allows.
- Conductive hydrogel (CH) coatings have been used to increase the safe charge injection of Pt [1].
- However, implant studies suggest that non-conductive scar tissue remains a problem, reducing electrode efficacy.



- It has been proposed that a "living electrode" (LE) with cells integrated within the electrode coating, shown in Figure 1, will greatly assist in reducing scar tissue.
- As the cell laden layer degrades, it is expected that the cells will form a matrix which will promote better charge conduction between the body and the implant [2].

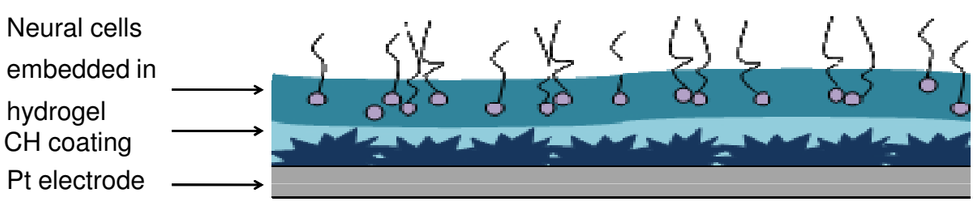


Figure 1. Schematic of layered "living electrode" design.

Aim

To explore the biosynthetic hydrogel, poly(vinyl alcohol) with phenol (PVA-ph) crosslinks to biological polymers, as a potential coating to improve the performance of CH electrodes.
To achieve this, the sub aims are:

- ✓ To assess neural cell viability following encapsulation in PVA-ph.
- ✓ To assess the effect of this coating on the CH electrical properties.

Method

- Three hydrogel variants were fabricated to investigate the optimal biomolecule for LEs:
  5% PVA-ph and 5% gelatin (mammalian protein),
  9% PVA-ph and 1% sericin (silk worm cocoon protein)
  8% PVA-ph and 1% sericin and 1% gelatin.
- The layered construct in Fig 1 was produced and electrically characterised by cyclic voltammetry (CV) and impedance spectroscopy (IS) compared to platinum and CH controls.
- Rat adrenal gland phaeochromocytoma (PC12) neural cells were encapsulated in each gel type at 2 x 10^6 cells/ml. A live-dead stain was used to determine viability at 12 days.

Manufacturing Process

- LE samples were prepared on 13 mm diameter Pt disks.
- Hydrogel coatings were pipetted on the CH and a coverslip was placed on top to ensure a thin and even coating. Samples were photopolymerised under visible light for 3 minutes.
- Due to the hydrophilicity of gelatin, samples which contained gelatin delaminated from the Pt electrode upon removal of the coverslip, as seen in Fig 2 a and c.

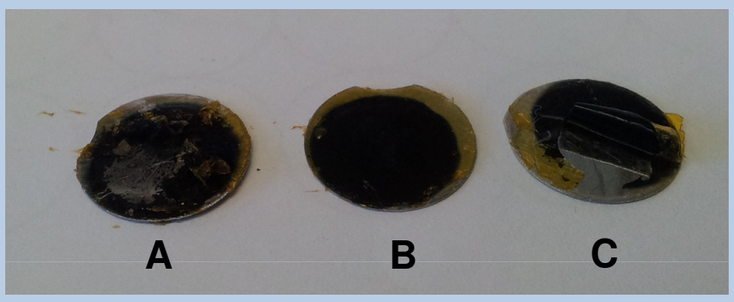


Figure 2. Prepared Samples with A)8% PVA-ph, 1% sericin and 1% gelatin. B) 9% PVA-ph and 1% sericin. C) 5% PVA-ph and 5% gelatin.

- Due to the inability to collect data from samples containing gelatin, further research was conducted with only PVA-ph and sericin samples.

Results

1. Cyclic Voltammetry

Table 1 shows the charge storage capacity calculated from CV spectra. Addition of the LE layer to the CH increases the charge storage capacity by a factor of 2 due to ion partitioning properties of hydrogels.

Table 1. Charge Storage Capacity of different electrodes

Electrode	Charge Storage Capacity (mC/cm²)
Platinum (Pt)	0.91 +/- 0.16
CH	24.96 +/- 3.96
Living electrode	50.00 +/- 8.71

2. Impedance Spectroscopy

The LE shows similar impedance magnitude to the CH and is orders of magnitude less than Pt, as shown in Figure 2.

The LEs have a zero degree phase lag in the biologically important region from 100 – 1000 Hz.

These results indicates the LE has electrical properties well suited to a bionic eye implant.

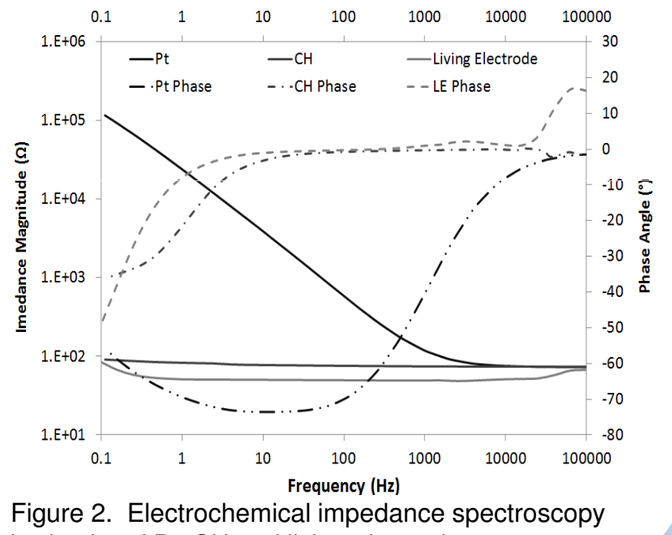


Figure 2. Electrochemical impedance spectroscopy bode plot of Pt, CH and living electrodes.

3. Cell Viability

Figure 3 depicts a live-dead staining of PC12 cells in a 9% PVA-ph and 1% sericin hydrogel after 12 days. Live cells are depicted as green and dead cells as red. The absence of red cells in Fig 3 shows that cell viability is excellent. Neurite extension also occurred, which is denoted by white arrows.

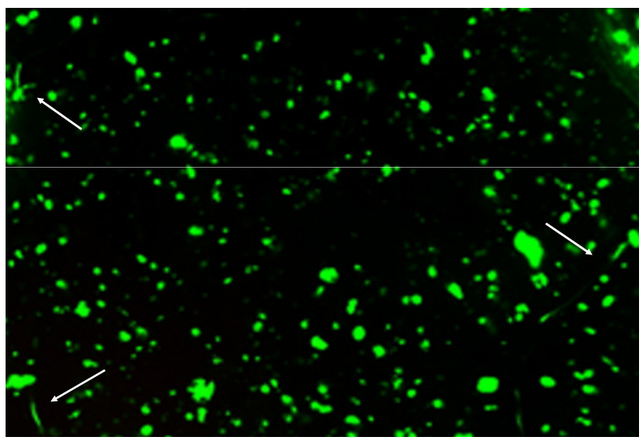


Figure 3. PC12 cell viability in 9% PVA-ph and 1% Sericin hydrogel at 12 days. Neural processes are denoted by white arrows.

Conclusion

A PVA-ph hydrogel with a small amount of sericin has shown great promise in promoting the growth and differentiation of neural cells. The electrical properties of the implant electrode have improved with the addition of the LE coating. This suggests that the living electrode concept is a viable path to miniaturising implant electrodes, facilitating the development of next-generation bionic implants.

The Future

- Longer term stimulation studies will determine cell viability and electrical characteristics with active electrical stimuli.
- Development of tailored electrical and mechanical properties to support different neuronal cells, such as stem cells.
- Cell studies to determine the feasibility of developing synapses to target tissue.

References

1. R.A. Green, et al., *Sci. Technol. Adv. Mater.*, 11 (2010) 014107 (13 pp)
2. R.A. Green, et al., Conf. Proc., *IEEE EMBC*, 2013 (4 pp).