Bionic eyes: deciphering the neural circuitry of vision restoration

BY MUHAMMAD KHURSHEED ULLAH KHAN MARWAT

As the boundaries between technology and biology blur, retinal prosthetics, often dubbed 'bionic eyes', present a ground-breaking paradigm shift in addressing blindness. This article delves into the captivating scientific intricacies of these neural interfaces, exploring their mechanisms of action, current limitations, and future frontiers.

Decoding the vision pathway

The visual pathway starts with light striking the retina's photoreceptor cells, rods and cones. These specialised cells undergo phototransduction and these signals then synapse onto retinal ganglion cells (RGCs), the workhorses of the visual system. The RGCs process and integrate visual information before transmitting it through the optic nerve to the visual cortex in the brain. The visual cortex deciphers these signals, constructing our perception of the world. Bionic eyes aim to bypass damaged photoreceptors and directly interface with surviving RGCs, rekindling the dormant circuitry of the visual pathway.

Several different types of retinal implants are in different stages of development; however, some notable mentions are:

1. Orion Visual Cortical Prosthesis System by Vivani Medical, Inc. (formerly Second Sight Medical Products): This investigational implant is specifically designed for Stargardt's disease, a form of retinal degeneration affecting central vision. It uses a smaller microelectrode array targeted to the macula, aiming to restore central vision without interfering with peripheral vision [1].

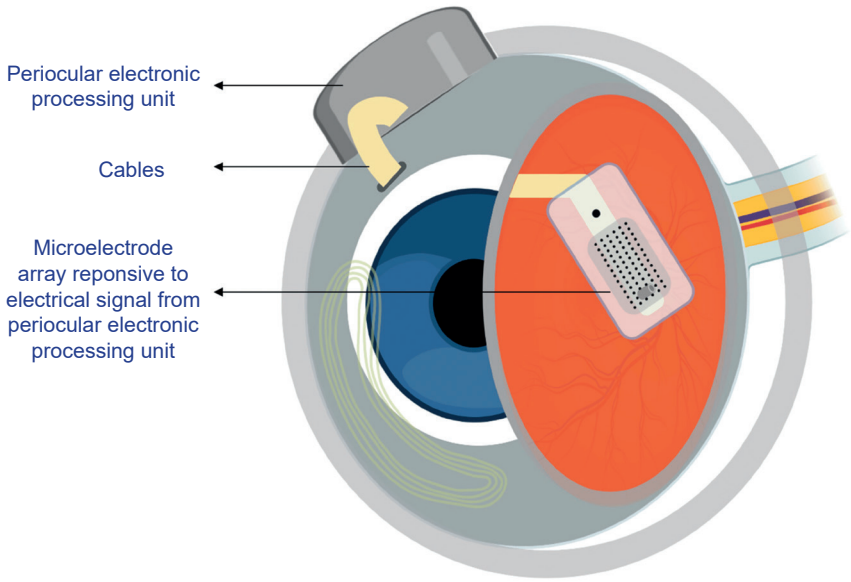

Figure 1: Intraocular Implant system of ARGUS II System [5].

2. Boston Retinal Implant Project (BRIP): This research project, led by Massachusetts Eye and Ear, has led to the formation of Bionic Eye Technologies which is developing a novel subretinal implant with high-density electrodes and wireless power transmission. They are striving to achieve even higher resolution and a wider field of view compared to existing implants [2,3].
3. Nano Retina: This company is working on a subretinal implant called 'Science Eye' that integrates light-sensitive opsins with the electrodes. These opsins, similar to those found in natural photoreceptors, could potentially offer even more natural and high-fidelity vision restoration.
4. Retinal pigment epithelial cells produced using stem cells have been implanted into retinae of the patients with visual loss as a result of wet age-related macular degeneration (AMD) and have recently been used to regain vision in a trial led by Professor Pete Coffey from University College London and Professor Lyndon da Cruz, a Retinal Surgeon at Moorfields Eye Hospital NHS Foundation Trust, London [4].

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The basic components of a bionic eye include but are not limited to...

1. Microelectrode arrays

At the heart of bionic eyes lies the microelectrode array (MEA), a tiny lattice of electrodes meticulously placed on the retina [5]. These electrodes act as neural transducers, directly stimulating RGCs with precisely timed electrical pulses. The challenge lies in mimicking the complex patterns of activity generated by healthy photoreceptors. Researchers are actively investigating various stimulation methods, including:

- Epiretinal stimulation: targeting RGCs located on the surface of the retina,

offering relatively straightforward surgical implantation.
- Subretinal stimulation: placing electrodes closer to the photoreceptor layer, potentially enabling higher fidelity vision but requiring more complex surgery.
- Optogenetic stimulation: utilising genetically modified RGCs that express light-sensitive opsins, allowing for activation with specific wavelengths of light and potentially leading to more natural vision restoration.

2. The processing unit

The processing unit acts as the bionic eye's brain, analysing video captured by a camera-equipped pair of glasses. This unit:
- Extracts crucial visual features like edges, shapes, and movement from the video data
- Encodes this information into specific patterns of electrical pulses tailored to stimulate distinct RGC populations
- Adjusts the stimulation parameters in real-time based on ongoing brain activity monitored through electrocorticography to personalise the visual experience.

3. Camera-equipped glasses

Captures visual information in the form of digital signals which is then transmitted to the processing unit.

While full sight restoration remains an ambitious goal, bionic eyes have demonstrably improved visual function in patients with retinal degenerative diseases including but not limited to AMD and retinitis pigmentosa. Individuals once enveloped in darkness can now perceive light, shadows, shapes, and even basic movement. This newfound ability enables them to navigate their surroundings with greater confidence, mobilise more safely and engage in basic tasks like reading large letters.

Elizabeth Jackson, a bionic eye recipient, described the impact of seeing her daughter's face again after 20 years of blindness as "a miracle." These stories highlight the profound impact of even rudimentary vision restoration on quality of life and independence. Different components of a bionic eye are illustrated in Figure 2.

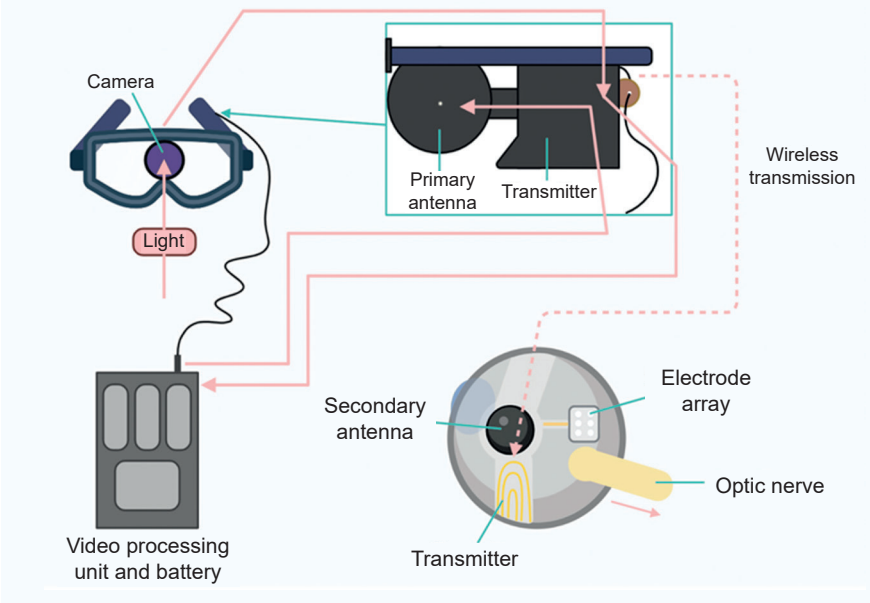

Figure 2: Schematic showing basic components and signal transduction pathway of ARGUS II System [5].

Facing the challenges: resolution, risks, and the long road ahead

Current bionic eye technology faces limitations. The low resolution offered by a limited number of electrodes results in a narrow field of view and limited detail recognition. Additionally, surgical procedures carry inherent risks, and the long-term effects of chronic electrode stimulation require further investigation. Despite these challenges, the field of retinal prosthetics is experiencing rapid innovation, and work is being carried on to:
- Improve electrode technology: increasing the number and density of electrodes to enhance resolution and expand the stimulated retinal area.
- Develop novel implant designs: exploring alternative approaches like light-sensitive opsins, mimicking the function of natural photoreceptors for potentially higher fidelity vision.
- Harness the power of brain-computer interfaces: bypassing the retina entirely and directly stimulating the visual cortex to create artificial vision.

Beyond the retina: brain-computer interfaces and bioartificial vision

The future of vision restoration may lie beyond the retina. Brain-computer interfaces (BCIs) aim to directly stimulate the visual cortex, bypassing damaged retinal circuitry entirely. Such BCIs could potentially offer higher resolution and a wider field of view, opening doors to a future where bioartificial vision transcends the limitations of our current prosthetic eyes.

Conclusion

Bionic eyes are not merely technological marvels; they represent a scientific feat with the potential to transform the lives of millions suffering from blindness. While challenges remain, the relentless pursuit of knowledge and innovation paints a future brimming with hope. As we decipher the intricate language of the visual pathway and unlock the secrets of neural coding, the day may come when sight, once lost, is restored, symphony by symphony, electrode by electrode.

References

1. Orion. *Cortigent*. https://www.cortigent.com/orion
2. *Boston Retinal Implant Project*. https://www.bostonretinalimplant.org
3. Products. *Bionic Eye Technologies*. http://www.bionicvisiontechnologies.com/products
4. da Cruz L, Fynes K, Georgiadis O, et al. Phase 1 clinical study of an embryonic stem cell–derived retinal pigment epithelium patch in age-related macular degeneration. *Nat Biotechnol* 2018;**36**:328–37.
5. Wu KY, Mina M, Sahyoun J-Y, et al. Retinal Prostheses: Engineering and Clinical Perspectives for Vision Restoration. *Sensors* 2023;**23(13)**:5782.

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