World Journal of Pharmaceutical Science and Research
www.wjpsronline.com
Review Article
ISSN: 2583-6579
SJIF Impact Factor: 3.454
Year - 2024
Volume: 3; Issue: 2
Page: 277-284

THE FUTURE OF SIGHT: JOURNEY INTO BIONIC EYES

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Article Received: 3 March 2024 ǀǀ Article Revised: 24 March 2024 ǀǀ Article Accepted: 15 April 2024

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DOI: 10.5281/zenodo.11141769

ABSTRACT

The goal of helping those who are blind or have severe visual impairments see again has resulted in impressive progress in the field of bionic eye technology. This review paper offers a thorough analysis of the state-of-the-art in bionic eye systems, emphasizing their functionality, clinical uses, design, and potential future developments.

The review begins with an examination of the fundamental ideas and technologies, such as cortical implants, retinal prostheses, and optic nerve stimulation devices. It then emphasizes how biomedical engineering, materials science, and neurophysiology are intricately integrated to allow these devices to replicate the natural visual process.

KEYWORDS: Artificial vision, bionic eye, retinal prosthesis, visual prosthesis.

INTRODUCTION

The aim of vision research has been to give blind people a functional level of vision again since the 1950s. Between 32 and 39 million individuals worldwide are blind, and cataracts and uncorrected refractive error are the most common and curable causes.[1] Patients with retinal diseases including age-related macular degeneration (AMD) and inherited dystrophies like retinitis pigmentosa (RP) that cause blindness frequently have relatively undamaged optic nerve and inner retina, making them candidates for retinal vision prosthesis.[2] These devices are specifically made to use sensory data from the remaining senses—like touch and hearing—in place of vision.[3] This makes it possible for a blind person to engage with their surroundings. It is not appropriate to leave up to chance the adaptive techniques and systematic training required to interpret recently acquired visual perceptions that eventually translate to functional vision that is helpful.[4]

History of Bionic Eye Technology

When Otfrid Foerster discovered that electrical stimulation of the occipital cortex resulted in a participant seeing a phosphene (a spot of light created by direct stimulation of the visual system), the path toward artificial vision restoration officially started in 1929.[5]

For more than a century, people with vision impairments have been able to restore their vision via the use of technology. But it wasn't until the development of contemporary electronics and downsizing methods that the concept of a bionic eye started to take shape. Georg von Bekesy, a German scientist, carried out the first effective electrical stimulation-based eyesight restoration experiment in 1929.

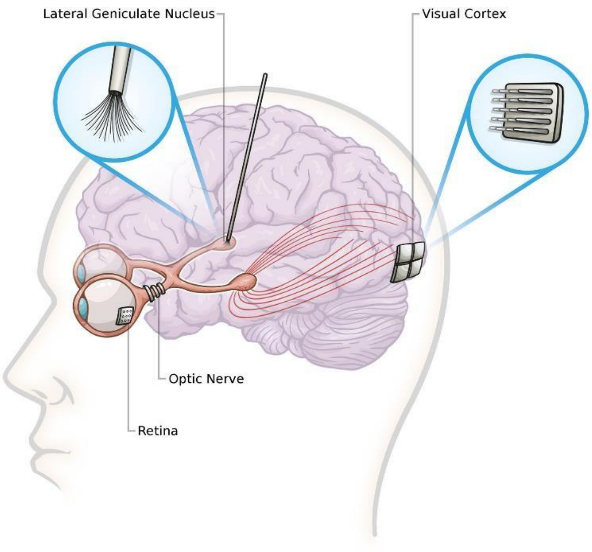
He stimulated the optic nerve of a blind patient with electrical currents, and the patient reported seeing flashes of light. This was the first evidence that the brain could produce visual perceptions through electrical stimulation. Photoreceptors are specialized cells found in the retina that convert light into electrical impulses that are delivered to the brain. This information was discovered in 1956 by Stephen Kuffler and Horace Barlow.[6,7]

Visual prostheses

A visual prosthesis, sometimes known as a bionic eye, is a test visual aid designed to let people who are partially or completely blind see again. Numerous technologies have been created, most of which are based on the neural prosthesis known as bionic ear devices or cochlear implants, which have been in use since the mid-1980s.[8]

Restoration of vision is not possible in cases where there is severe eye destruction, such as phthisis bulbi. In the normal visual pathway, light passes through the tear film, cornea, aqueous, pupil, lens, and vitreous to activate the light-sensitive photoreceptors and set up the trans-synaptic connections of the retina.

However, in cases when blindness results from a disease affecting the retina's photoreceptors, such as Retinitis Pigmentosa (RP), another method of vision rehabilitation entails electrically stimulating the visual pathway directly in order to produce functionally effective visual perception.[9]



A graphical representation of the electrical stimulation targets and visual pathways for the development of a visual prosthesis is shown in Figure 1. It is possible to implant small arrays of electrodes suprachoroidally, subretinally, or epiretinally in order to activate retinal ganglion cells and produce phosphenes.

A primary focus of visual prostheses is the retina. Electrical stimulation can be directed towards different retinal structures, such as the layer of retinal ganglion cells whose axons comprise the optic nerve, the inner layer of bipolar cells, and the outer layer of light-sensitive photoreceptor cells.[10]

Cortical prosthesis

Certain visual prostheses are positioned completely away from the retina. These consist of implants on the optic nerve or in brain regions like the thalamus or visual cortex. On the surface of the brain's visual cortex, for instance, implants such as the Gennaris by Monash Vision Group or the Orion by Second Sight are made. Patients with glaucoma, optic nerve damage, IRDs, AMD, and other eye diseases may be able to receive treatment using these devices.

Based on Foerster's ideas, Giles Brindley and Dobelle pioneered all later work in the field of developing visual prostheses. They showed that electrical stimulation of the occipital brain by implanted electrodes might elicit phosphenes and patterned perceptions.[11] In an attempt to address the drawbacks of surface stimulation using low current high-fidelity systems, intracortical stimulation was developed. This is because the majority of the visual cortex is located deep within the calcarine fissure and is not accessible to cortical surface electrodes. An alternative method entails integrating a light-sensitive component (such photodiodes) inside the implant and combining it with an electrode array that stimulates the body directly into one unit.[12,13] In a particular version of this method, a tiny infrared projector installed on glasses sends picture data to the combined photodiode/electrode array. The light from the projector is then transformed into electrical energy, which powers the electrodes.[13]

Optic nerve prosthesis

The optic nerve is a desirable site for the installation of a visual prosthesis because it represents the complete visual field in a small, surgically accessible area that provides a suitable anatomic location for an implant. On the other hand, the optic nerve is a highly organized neurological tissue that has 1.2 million axons arranged in a cylinder with a diameter of 2 mm. Dissection of the dura is necessary for surgical manipulation of this region, which carries a risk of infection and potentially stops blood flow to the optic nerve.[3] The entire perimetry is consequently contained in a single, small region, which is the primary advantage of optic nerve prosthesis. In order to provide visual stimulations, an optic nerve implant is equipped with specialized spiral cuff electrodes that carry impulses from a camera through the optic nerve.[14]

Retinal prosthesis

The post-mortem morphometric examination of the retina from patients with end-stage RP provides the foundation for the retinal prosthesis; it shows that 78.4% of inner nuclear and 29.7% of ganglion layer cells were preserved while just 4.9% of photoreceptors were.[15] Additionally, 93% of RGCs were spared in legally blind neovascular AMD patients, and there was a 10% increase in inner nuclear layer cells.[16, 17]

The area of the retina is responsible for detecting and transmitting light signals. It is composed of numerous cell types, each of which has a distinct function in vision. When photoreceptor cells detect light, an electrical signal is initiated. An image is created in the brain after the information travels via the optic nerve, the middle layer of retinal cells, and the brain itself. Many forms of retinal degeneration, including inherited retinal illnesses including RP, choroideremia, Leber congenital amaurosis, and AMD, result in vision loss due to damage or death of photoreceptor cells.[18]

An artificial retina is what a retinal prosthesis does. It functions to restore the function of photoreceptors that retinal degeneration has destroyed. The prosthesis gathers light and transforms it into an electric signal using parts including cameras, computers, and electrodes. The brain uses this signal to construct a fresh visual simulation. This contrasts with low-vision devices or implanted lenses, which aim to enhance a person's current visual abilities.

Epiretinal prosthesis

In order to stimulate the retinal neurons that are still alive, epiretinal implants use imaging equipment like cameras to convert visual information into patterns of electrical stimulation.[11]

An illustration of an epiretinal prosthesis is the Argus II. It is made up of a tiny camera installed in glasses and a microchip inserted into the front of the retina. After taking a picture, the camera transforms it into an electrical impulse that is wirelessly transmitted to the electrodes. The remaining retinal cells are stimulated by the impulses, and the brain receives messages from them. These signals are subsequently translated into an image by the brain. Patients may eventually be able to see somewhat normally again.

Sub-retinal prosthesis

The sub-retinal prosthesis provides an appealing way for individuals with AMD and RP to improve their vision because it is powered solely by micro photodiodes, or solar cells. But at the moment, a number of restrictions prevent this technology from fulfilling its potential as a visual prosthesis. The current generation of photodiode arrays lacks the energy efficiency necessary to produce enough electricity to stimulate bipolar cells.[14]

Sub-retinal prostheses like the Alpha IMS and Alpha AMS are examples. At the moment, Canada and the US do not approve of them, but Europe does. A silicon chip is inserted behind the retina in these devices. It is linked to an external power pack that boosts the light signal as well as a tiny computer hidden behind the ear. You can wear this power supply around your neck. These gadgets have less computing power but are less bulky because they do not require external glasses.

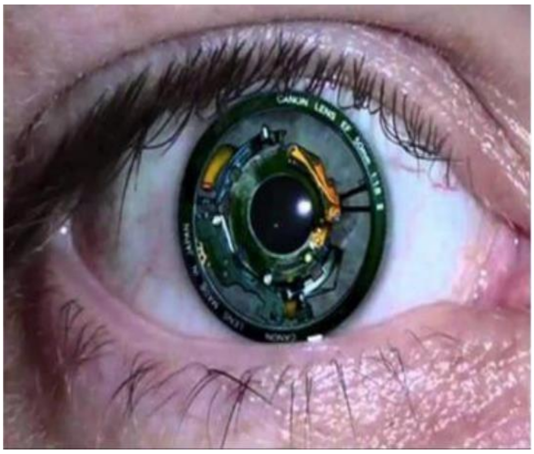
Working of bionic eye

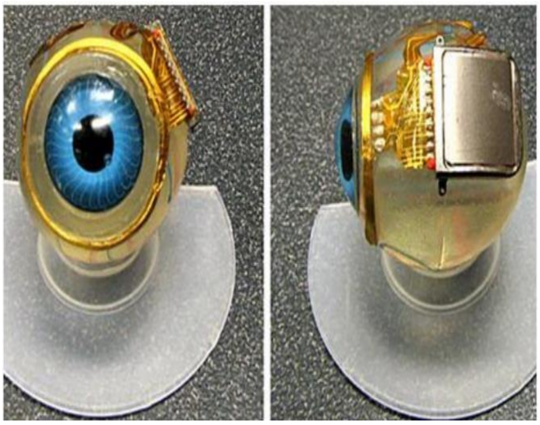
Operate on the same fundamental idea of stimulating the brain with electricity to create visual perceptions (see Figure 1). Retinal implants, which are intended to replace the function of injured or destroyed photoreceptor cells in the retina, are the most prevalent type of bionic eye.

These cells transform light into electrical signals, which are then transmitted to the brain and processed into visual images.[6]

A small array of electrodes is inserted into the retina to form retinal implants. These electrodes are attached to a tiny camera that is fixed on the patient's glasses. Images are taken by the camera and transmitted to a tiny computer that the patient wears, which interprets the data and transmits impulses to the electrodes in the implant. The retina's remaining healthy cells are activated by tiny electrical currents produced by the implant's electrodes. After that, the brain interprets the impulses that these cells send as visual images.

Numerous parameters, such as the quantity and positioning of the electrodes, the camera's resolution, and the computer's processing algorithms, can significantly affect the quality of the visual images generated by retinal implants.[7,8]





Comprehensive overview of the current state, challenges

Higher-order algorithms and image-processing methods will improve the resolution and quality of the visual data that is sent to the brain. Furthermore, enhancing the implants' lifetime and biocompatibility will boost patient acceptance and reduce the possibility of problems. The restricted number of electrodes and the difficulty of connecting the implant to the visual system are two obstacles that still need to be overcome, but they should be resolved with continued study and innovation.

Global marketing

In India, there is a growing demand for bionics—the fusion of electronics and biology. Although bionics is still in its early phases of development, many medical facilities prefer to use it over organ transplants or more conventional techniques such utilizing a wooden limb, marble, or glass eye.

Right now, North America controls the majority of the world market for a number of reasons, including greater knowledge, a higher per capita income, and an Argus II patent. Europe and Asia- Pacific lead after North America. The Asia-Pacific market is fully occupied and has only been partially penetrated. Since 2012, the market has been expanding, and in the next years, a boom is anticipated. Regretfully, less people are aware of the bionic eye than one might think.[19]

The Bionic Eye Market Analysis by types is segmented into:

Electronic Mechanical

There are two categories in the bionic eye market: mechanical and electrical. Electronic bionic eyes enable blind people to restore partial or whole vision by sending visual signals from a camera to the brain using cutting-edge technologies like microchips and wireless connection. Conversely, mechanical bionic eyes generate visual perception by means of mechanical components stimulating the retina. Both technologies seek to enhance the quality of life for those who are blind or visually impaired by artificially recovering their eyesight.

The Bionic Eye Market Industry Research by Application is segmented into:

Hospitals Clinics

Hospitals and clinics are seeing a growth in the bionic eye sector, where it finds a variety of uses. People who are blind or visually impaired can have bionic eyes implanted to improve or regain their eyesight. Patients suffering from visual loss from retinitis pigmentosa, age-related macular degeneration, or other eye disorders have hope thanks to these medical devices. Hospitals and clinics are essential for diagnosing conditions, determining whether a patient is a good candidate for these implants, performing operations, and offering post-operative care. Their facilities and experience are crucial in furthering the application of bionic eyes to enhance patients' quality of life.

Current State

Technological Diversity: Retinal prostheses, visual nerve stimulation, and cortical implants are only a few of the methods that make up bionic eye technology. People with retinitis pigmentosa and other retinal degenerative illnesses have shown promise in regaining limited vision with devices like the Alpha IMS retinal implant and the Argus II Retinal Prosthesis System.

Clinical Applications: With differing degrees of success, bionic eye devices have been tried in clinical trials across the globe. Though some users claim better quality of life and visual perception, there are still issues with attaining high-resolution vision, enlarging the range of view, and guaranteeing long- term gadget stability.

Research Developments: Bionic eye technology has improved as a result of recent developments in neuroscience, electronics, and materials science. This includes improving knowledge of the brain's visual processing mechanisms, miniaturizing electronics, and creating more biocompatible materials for implantable devices.

Challenges

Resolution and Vision Quality: In comparison to natural vision, the resolution and visual acuity of current bionic eye technologies are restricted. Enhancing the visual signal's resolution and clarity is still a major problem, especially for devices that aim to treat disorders like age-related macular degeneration.

Biocompatibility and Longevity: The effectiveness of implanted devices depends on ensuring their biocompatibility and long-term stability. Bionic eye implants face issues related to electrode degradation, tissue inflammation, and device encapsulation that affect their durability and dependability.

Surgical intricacy and safety: Bionic eye device implantation necessitates invasive surgical techniques, which are inherently dangerous. There are constant difficulties in the profession to minimize surgical complexity, lower the risk of complications, and optimize postoperative rehabilitation.

Future Directions

High-Resolution Vision: Upcoming bionic eye technologies seek to get closer to the degree of natural vision by achieving more fidelity and resolution. This entails creating increasingly complex electrode arrays, refining stimulation schemes, and incorporating cutting-edge signal processing techniques.

Biological Interfaces: New research investigates how to better integrate bionic eye technologies with the human visual system by using biological interfaces, such as optogenetics and synthetic biology. These methods have the potential to improve the longevity and effectiveness of bionic eye implants.

Systems that are Wireless and Self-Powered: In order to minimize the need for external components and improve user convenience, future bionic eyes may include wireless communication and self- powered features. This involves investigating cutting-edge ways for wireless data transmission and energy harvesting.

Neural Interface Technologies: New developments in neural interface technologies present prospects for enhancing the integration of bionic eye devices with the brain's visual processing pathways. Examples of these include brain-computer interfaces and neuroprosthetics.

Clinical Translation and Accessibility: Coordinated efforts in regulatory approval, clinical validation, and commercialization are necessary to close the gap between research prototypes and clinically feasible bionic eye solutions. Maintaining fair access to bionic eye technology for people all around the world is still a top objective.

CONCLUSION

Bionic eyes represent a remarkable advancement in medical technology, offering hope to millions of individuals affected by vision impairment. Through the integration of cutting-edge engineering and biological principles, these devices hold the potential to restore partial or even full vision to those who have lost it due to various ocular conditions. While challenges remain, including improving resolution and enhancing compatibility with the human visual system, ongoing research and development efforts promise further improvements in the future. Overall, bionic eyes stand as a testament to the power of interdisciplinary collaboration and innovation in addressing complex medical challenges, offering a brighter outlook for individuals living with visual impairment.

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