BIONIC EYE PROSTHESIS

Dr. K. Lokesh Sai, Dr. Subhabrata Maiti

INTRODUCTION

At least 2.2 billion people worldwide suffer from near or far vision loss. At least 1 billion of these people have preventable or untreated blindness. The leading cause of vision loss and blindness worldwide is poor vision and cataracts. Worldwide, it is estimated that only 36% of people with farsightedness due to nearsightedness and only 17% of people with nearsightedness due to cataracts receive appropriate care.
Visual impairment is a burden on the global economy with an estimated annual global production cost of $411 billion. Visual Impairment affects people of all ages; But most people who are blind are over the age of 50. [1]

At least 1 billion (or nearly half) of these cases, vision impairment could have been prevented . Among these 1 billion people, diseases that cause vision impairment or blindness include cataracts (94 million), refractive errors (88.4million), age-related macular degeneration (8 million), glaucoma (7.7 million), diabetic retinopathy (3.9 million) [2]. The most common cause of near vision impairment is presbyopia (826 million) [3].

Retinal diseases such as retinitis pigmentosa (RP), which affects 1 in 4000 or 0.025% of the population, occur mainly in age-related macular degeneration (AMD), which affects approximately 5% of working age [4,5]. It is an important cause of blindness in the world [6,7]
Cone dystrophy, anchoroidemia, and Stargardt's disease are also special areas where researchers work on the bionic eye [8,9]. There are currently many research groups worldwide working to develop optical systems that cover all possible areas in the visual pathway. It is reported that nearly 20 research groups based in the United States, Australia, Germany, Japanand France are working on the spinal cord in different plants. Clinical trials of these devices have shown that they can improve visual acuity and/or the ability to perform activities of daily living [10]

Principles of Natural Vision

To create a bionic eye, it is important to learn about the process in which light is absorbed, and is converted into electrical impulses and encoded into nerve signals. Light passes through the cornea, iris, and lens, helping the light focus on the photosensitive retina. Retinal cells have photoreceptors (PRs), rods, and cones, through which photochemical reactions convert light into electrical nerve signals through stimulation of retinal ganglion cells (RGC). About 120 million rods in each eye are sensitive to low levels of light [11], while the 6 million cones responsible for color vision work best in bright light [12]. RGCs have 1 million axons that run from the optic

nerve to the lateral geniculate nuclei (LGN) in the thalamus. LGN is a complex hierarchical structure in which each segment receives axons from a particular ganglion cell type. Before projecting to the first visual cortex, where all the higher cognitive processing takes place, a certain degree of vision occurs [13] by affecting the power of the retina, and high spatial and temporal solutions can be obtained in various colors and contrasts. .

Recognition of objects and geometric patterns, appreciation of distance, direction, and movement, and coordination of visual interpretation with other senses and motor skills may be due to integration of the neural cortex. The complex process of capturing , assimilating, compressing and processing enormous amount of visual information takes place in a millisecond.

What is the working principle of the bionic eye?

The bionic eye, also known as visual prostheses, is a device designed to help blind people see again. There are many types of bionic eyes, but they all work on the same principle; uses electrical stimulation to stimulate vision in the brain.

The bionic eye - how it works

First prototype: Wide-view neurostimulator

BIONICVISION
AUSTRALIA

1. Camera captures image and transmits data to an external, body worn processing unit

4. Implanted electrode array stimulates retina

5. Electrical signals sent from retina via visual pathway to vision processing centres in the brain

3. Implanted receiver passes signals onto retinal implant

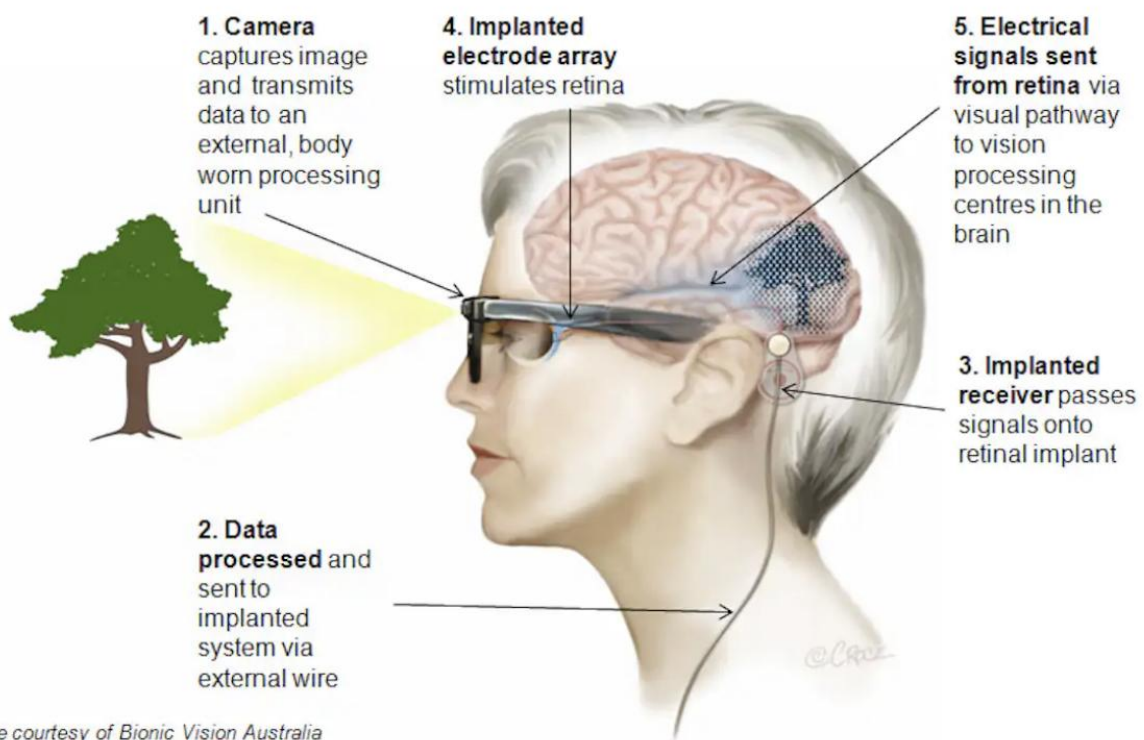**2. Data processed** and sent to implanted system via external wire

Image courtesy of Bionic Vision Australia

This image shows bionic vision technology and it is based on a camera that captures images, processes them and sends data to a retinal implant. This implant contains a number of electrodes that stimulate the remaining cells of the retina to elicit the perception of vision.
(Image source: Bionic vision Australia)

The most common types of bionic eyes are retinal implants designed to replace the activity of damaged photoreceptor cells in the retina. The retina is a thin layer of tissue at the back of the eye that contains special cells called photoreceptors. These cells convert light into electrical signals that are sent to the brain and translated into visual images[14,15,16]. In people with damaged retinas, photoreceptor cells cannot function properly, resulting in vision loss. The retinal implant works by bypassing the damaged photoreceptor cells and directly supporting the cells that remain in the retina. A retinal implant consists of a series of small electrodes that are implanted into the retina. These electrodes are connected to a small camera mounted on the patient's glasses. The camera captures the image and sends it to a small computer that the patient wears, which processes the image and sends a signal to the electrodes on the implant. When the electrodes in the implant are stimulated, they produce small electrical currents that activate other cells in the retina. These cells then send signals to the brain, where they are interpreted as visual images.

The quality of the visual images produced by retinal implants can vary depending on many factors such as the number and location of the electrodes, the resolution of the camera, and the technique of working with the computer. Most retinal implants currently only produce very low resolution images, but scientists are trying to develop technology that will provide detailed and natural vision. In addition to retinal implants, there are other types of bionic eyes that work differently. For example, optic nerve implants are designed to directly support the brain, bypassing the damaged retina. Cortical implants, on the other hand , are designed to directly support the visual cortex of the brain, bypassing the retina and optic nerve.
Regardless of the specific type of bionic eye, all of these devices work by using electrical stimulation to stimulate vision in the brain. While the technology is still in its early stages, the bionic eye has the potential to improve the lives of the blind and could one day lead to fully functional vision.

Types of Bionic Eyes.
There are many types of bionic prostheses, each targeting a specific field of view [17,18,19,20,21]. The are retinal implants , optic nerve implants, and cortical implants, each with their own advantages and disadvantages [22,23,24,25,26].

A. Retina Implants
Retina implants are the most commonly used type of bionic eye. It is designed to treat blindness in patients with retinal degenerative diseases such as retinitis pigmentosa and age-related

macular degeneration. A retinal implant consists of a small camera mounted between two glasses and an array of electrodes implanted into the retina. The camera captures the image, which is then processed and sent to the electrode device.

The array supports the retina, creating visual images that are sent to the brain. Retinal implants have shown promising results inclinical trials; many patients reported improvement in visual function. However, the quality of the images produced by this device is still limited and the technology is not suitable for all types of vision loss.
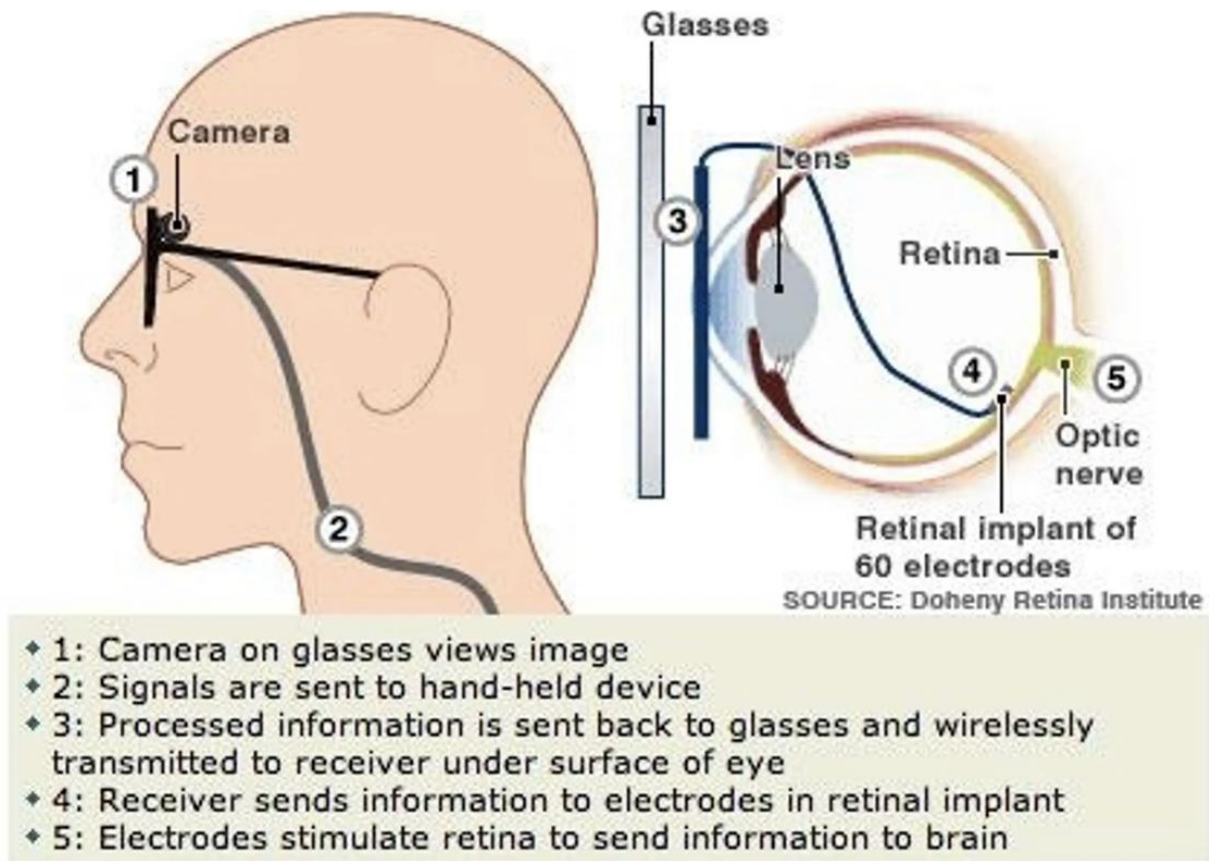

* 1: Camera on glasses views image
* 2: Signals are sent to hand-held device
* 3: Processed information is sent back to glasses and wirelessly transmitted to receiver under surface of eye
* 4: Receiver sends information to electrodes in retinal implant
* 5: Electrodes stimulate retina to send information to brain

Image showing transmission of data in retinal implants
(Image source: Doheny Retina Institute)

Advantages
1. Retinal implants can restore some vision functions in people with retinal degenerative diseases such as retinitis pigmentosaand age-related macular degeneration.
2. Retinal implants are also non-invasive because the implant is placed in the eye and does not require brain surgery.
3. The technology has been around for a while and is maturing through clinical trials.

Disadvantages:
1. The image quality produced by the retina implant is limited and patients may experience degradation, lack of resolution, and difficulty seeing faces.

2. This prosthesis is not suitable for all types of visual impairment and not all patients are candidates for implants.
3. Retinal implants require surgery that carries certain risks and complications.

B.Optic Nerve Implants

The Optic Nerve Implant is designed to assist in regaining vision in patients with optic nerve damage due to glaucoma, optic neuritis , or other conditions. Optic nerve implants consist of an array of electrodes implanted in the brain. The array supports the nerves that produce visual images that are transmitted to the brain. Optic nerve implants are still under development and clinical trials have yet to yield results. But the technology shows great promise for people with brain damage whose treatments are currently limited.
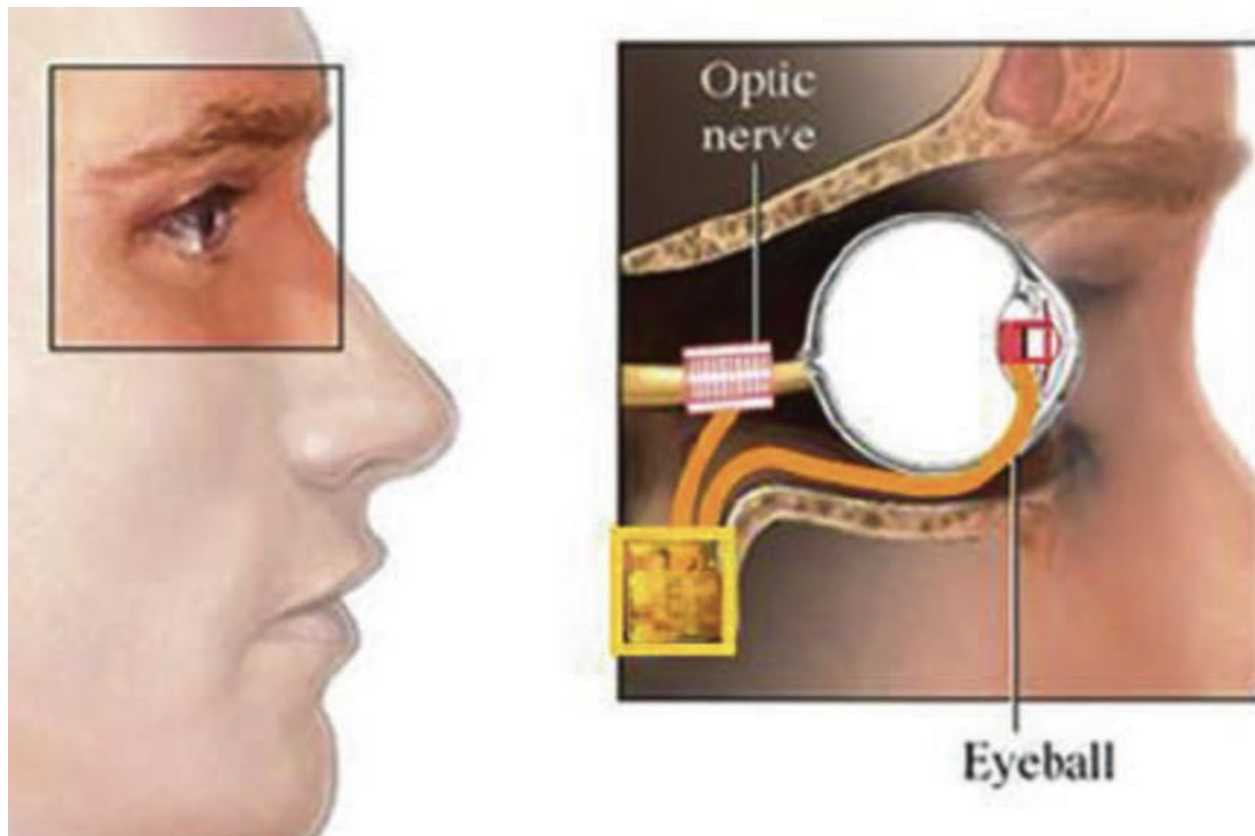

Figure shows Optic nerve visual prosthesis using penetrating microelectrode arrays

Advantages:
1. Optic nerve implants can restore some degree of visual function to patients with optic nerve injuries that are currently difficult to treat.
2. The implant is non-invasive as it is placed in the optic nerve and does not require brain surgery.
3. This device can provide better images than retinal implants.

Disadvantages:
1. The technology is still in the early stages of development and clinical trials have yet to show results.
2. Optic nerve implants may not be suitable for all types of optic nerve injuries and not all patients are candidates for optic implants.

C. Cortical Implants

Cortical implants are designed to help restore vision in people with damage to the visual cortex (the part of the brain that processes visual information). Cortical implants contain arrays of electrodes implanted in the eye cortex. The array creates visual images that the patient sees by stimulating the cortex.

Cortical implants are still in development and clinical trials have yet to yield results. But the technology holds great promise for people with facial damage whose treatments are currently limited.
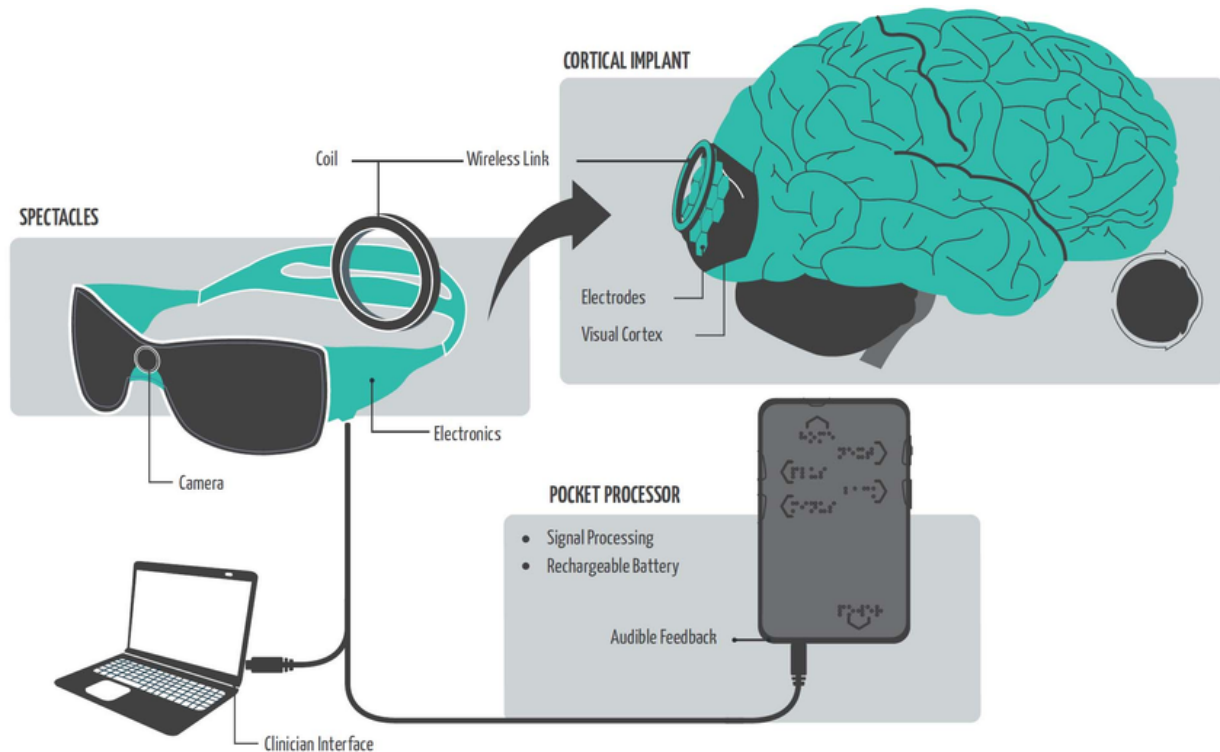

Image shows an overview of MVG cortical visual prosthesis

Advantages:
1. Cortical implants have the potential to treat blindness in people with the visual cortex, a condition that is currently difficult to treat.
2. The implant is non-invasive as it is placed in the eye cortex and does not require eye surgery.

3. This technology can provide better images than nerve and nerve implants.

Disadvantages:
1. The technology is still in the early stages of development and clinical trials have yet to show results.
2. Cortical implants may not be suitable for all types of visual cortical damage and not all patients are candidates for cortical implants.

Challenges while developing bionic eye.

Despite advances in technology, some drawbacks need to be addressed in order for bionic eye prostheses to be considered a good treatment [27]. The limitation of electrode geometry must be taken into account as it relates to the amount of current that can be delivered to the target tissue in a safe location. The theoretical solution is adversely affected when the electrodes are placed close together. In addition, the effects of long-term and local electrical energy on the nervous tissue are still unknown due to the prosthesis being worn and used for a long time. Another problem to be solved is how to relate the captured image to the natural movement of the eye. Improper use of the eye may cause a sense of confusion, causing patients to incorrectly locate objects in the outside world. This confusion is especially true for designs that use external cameras. Therefore, complex eye tracking mechanisms have been proposed and designed to create appropriate movements in the image [28].

Future directions in bionic eye research.
Bionic eye research and development is a rapidly growing field with great potential to improve the lives of the visually impaired [29,30,31,32,33,34,35,36]. As technology continues to advance, bionic eye research will go in many directions in the future. Improved image quality: One of the main challenges of bionic eyes is the natural vision-like design of images. Future research will focus on improving image quality by increasing the number of electrodes, developing new stimulation strategies, and combining advanced image processing algorithms.
Wireless communication: Currently, most bionic eye implants require cables to transmit messages to and from the device. Future research will focus on the development of wireless communication devices to eliminate the need for cables and reduce the risk of infection and complications.
Miniaturization: As bionic eye technology continues to advance, researchers can focus on smaller implants to make them smaller, lighter, and more comfortable for patients.This will also reduce the risks associated with surgery [37].
Integration with intelligence: As we mentioned before, intelligence is used in the development of the bionic eye and design. Future research could expand intelligence with the bionic eye to improve imaging performance, extend device life, and improve overall implant function.

Multimodal sensory integration: Research is already underway to create sensory prostheses that can restore hearing, touch, and even smell. Future research will focus on combining the bionic eye with other sensory prostheses to create a multi-sensory experience.

Clinical and commercial trials: Despite significant advances in the use of the bionic eye, it is still largely experimental. Future research will focus on further clinical trials to evaluate safety and efficacy as well as the development of products that can be widely distributed to patients in need.

Conclusion.

There have been many advances in the treatment of visual impairment and blindness.The options, however, are limited once an individual has lost vision. The visual prosthesis is a radical and innovative approach in restoring vision to these individuals[38, 39].

The main purpose of visual prosthesis is to restore the vision of the blind, and when one is brave to believe, the challenges remain before it becomes reality. Based on recent developments and clinical research, there is good reason to believe we are on the path to achieve this goal.

References:

1. https://www.who.int/news-room/fact-sheets/detail/blindness-and-visual-impairment
2. GBD 2019 Blindness and Vision Impairment Collaborators; Vision Loss Expert Group of the Global Burden of Disease Study. Causes of blindness and vision impairment in 2020 and trends over 30 years, and prevalence of avoidable blindness in relation to VISION 2020: the Right to Sight: an analysis for the Global Burden of Disease Study. Lancet Glob Health. 2021 Feb;9(2):e144-e160. doi: 10.1016/S2214-109X(20)30489-7.
3. Fricke, TR, Tahhan N, Resnikoff S, Papas E, Burnett A, Suit MH, Naduvilath T, Naidoo K, Global Prevalence of Presbyopia and Vision Impairment from Uncorrected Presbyopia: Systematic Review, Meta-analysis, and Modelling, Ophthalmology. 2018 May 9.
4. Hartong DT, Berson EL, Dryja TP. Retinitis pigmentosa. The Lancet 2006; 368: 1795–1809.
5. World Health Organization (WHO). SpringerReference. DOI:10.1007/springerreference_70205.
6. Bunker CH, Berson EL, Bromley WC, et al. Prevalence of retinitis pigmentosa in Maine. Am J Ophthalmol 1984; 97: 357–365.
7. Klein R, Klein BE, Jensen SC, et al. The five-year incidence and progression of age-related maculopathy: the Beaver Dam Eye Study. Ophthalmology 1997; 104: 7–21.
8. Farvardin M, Afarid M, Attarzadeh A, et al. The Argus-II Retinal Prosthesis Implantation; From the Global to Local Successful Experience. Frontiers in Neuroscience; 12. Epub ahead of print 2018. DOI: 10.3389/fnins.2018.00584.

9. Mirochnik RM, Pezaris JS. Contemporary approaches to visual prostheses. Mil Med Res 2019; 6: 19.

10. Stronks HC, Christiaan Stronks H, Dagnelie G. The functional performance of the Argus II retinal prosthesis. Expert Review of Medical Devices 2014; 11: 23–30.

11. RS, Moritz OL. Photoreceptors at a glance. Journal of Cell Science 2015; 128: 4039–4045.

12. Pirenne MH. Rods and Cones. The Visual Process 1962; 13–29.

13. Deuchars S, Deuchars J. Neuroscience-a novelty for the nervous: Neuroscience (1997). Purves D, Augustine GJ, Fitzpatrick D, Katz LC, LaMantia A-S, McNamara JO (Eds). Sunderland, MA: Sinauer Associates, Inc. 562 pp. BioEssays 1998; 20: 871–872.

14. Finger, S. (2001). Origins of neuroscience: a history of explorations into brain function. Oxford University Press, USA.

15. Sarkar, P., & Joshi, A. (2023). Applied Mathematical Modelling in Evolutionary Biochemistry. Scandinavian Journal of Information Systems, 35(1), 68-75.

16. Joshi, A., Manik, R. K., Kumar, P., Roy, S., Jain, D., & Sarkar, P. (2022). Brain Fingerprinting: The New Era of Truth and Lie Detection. Advanced Engineering Science, ISSN, 2096-3246.

17. Nowik, K., Langwińska-Wośko, E., Skopiński, P., Nowik, K. E., & Szaflik, J. P. (2020). Bionic eye review–An update. Journal of Clinical Neuroscience, 78, 8-19.

18. Akhtar, N., Joshi, A., Singh, B., & Kaushik, V. (2021). Immuno-informatics quest against COVID- 19/SARS-COV-2: determining putative T-cell epitopes for vaccine prediction. Infectious Disorders- Drug Targets (Formerly Current Drug Targets-Infectious Disorders), 21(4), 541-552.

19. Joshi, A., Krishnan, S., & Kaushik, V. (2022). Codon usage studies and epitope-based peptide vaccine prediction against Tropheryma whipplei. Journal of Genetic Engineering and Biotechnology, 20(1), 41.

20. Joshi, A., Akhtar, N., Sharma, N. R., Kaushik, V., & Borkotoky, S. (2023). MERS virus spike protein HTL-epitopes selection and multi-epitope vaccine design using computational biology. Journal ofBiomolecular Structure and Dynamics, 1-16.

21. Joshi, A., Sasumana, J., Ray, N. M., & Kaushik, V. (2021). Neural network analysis. Advances in Bioinformatics, 351-364.

22. Zhang, H., & Lee, S. (2022). Robot bionic vision technologies: A review. Applied Sciences, 12(16),7970.

23. Joshi, A., & Kaushik, V. (2021). Big Data and Its Analytics in Agriculture. Bioinformatics for agriculture: High-throughput approaches, 71-83.

24. Joshi, A., Solanki, D. S., Gehlot, P., Singh, J., & Kaushik, V. (2022). In-Silico Validation of Prosopis ciniraria Therapeutic Peptides Against Fungal Cell Wall: Better Treatment Strategy for Fungal Diseases. International Journal of Peptide Research and Therapeutics, 28, 1-9.

25. Borkotoky, S., Joshi, A., Kaushik, V., & Jha, A. N. (2022). Machine Learning and Artificial Intelligence in Therapeutics and Drug Development Life Cycle. IntechOpen.

26. Vats,N.E.H.A.,Joshi,A.M.I.T.,Kour,S.A.R.A.N.J.E.E.T.,&Kaushik,V.I.K.A.S.(2021). Covid-19 pandemic: pathological, socioeconomical and psychological impact on life, and possibilities of treatment. International Journal of Pharmaceutical Research, 2724-2738.

27. Chader GJ, Weiland J, Humayun MS. Artificial vision: needs, functioning, and testing of a retinal electronic prosthesis. Progress in Brain Research 2009; 317–332.

28. Dr. Harini Sri, Dr. Subhabrata Maiti. BIOENGINEERING AN ARTIFICIAL EYE - A REVIEW-- Palarch's Journal Of Archaeology Of Egypt/Egyptology 17(7), 1457- 1474. ISSN 1567-214x

29. Paraskevoudi, N., & Pezaris, J. S. (2019). Eye movement compensation and spatial updating in visual prosthetics: mechanisms, limitations and future directions. Frontiers in systems neuroscience, 12, 73.

30. Joshi, A., Vats, N., Singh, H., & Kaushik, V. (2022). Quercetin Compound Analysis to Develop Treatment for Dementia Associated with Alzheimer? s disease in Humans: In-silico Study. Journal of Drug and Alcohol Research, 11(4), 1-7.

31. Krishnan, S., Joshi, A., & Kaushik, V. (2021). The Differentially Expressed Genes and Biomarker Identification for Dengue Disease Using Transcriptome Data Analysis. Journal of Drug and Alcohol Research, 10(6).

32. Joshi, A., Sharma, V., Singh, J., & Kaushik, V. (2022). Chemi-Informatic Approach to Investigate Putative Pharmacoactive Agents of Plant Origin to Eradicate COVID-19. Coronaviruses, 3(3), 40-54.

33. Joshi, A., Ray, N. M., Badhwar, R., Lahiri, T., & Kaushik, V. (2020). Application Of Hmm-Viterbi Model For Identification Of Epitopic Signature Within Screened Protein-Antigens Of Hepatitis C Virus. European Journal of Molecular & Clinical Medicine, 7(07), 2020.

34. Joshi, A., Kaushik, V., & Singh, J. (2019). Comparative Analysis of Genomic Data To Determine Codon Usage and Amino Acid Usage in Tropheryma Whipplei. Think India Journal, 22(16), 67-78.

35. Joshi, A., Roy, S., Manik, R. K., & Sahoo, S. K. (2023). Scientific Philosophy: Exploring Existential, Metaphysical, and Ethical Research Philosophy Behind the Question "WHO AM I?". Journal of Pharmaceutical Negative Results, 1648-1671.

36. Joshi, A., Dubey, S., & Kumar, P. (2022). Neurobioinformatics: A Novel Way For Exploring And Developing Brain Cancer Therapies. Journal of Pharmaceutical Negative Results, 8291-8295.

37. Sarkar, Proshanta & Dewangan, Omprakash & Joshi, Amit. (2023). A Review on Applications of Artificial Intelligence on Bionic Eye Designing and Functioning. Scandinavian Journal of Information Systems. 35. 10.5281/SJIS.775137.

38. Chakravarthy U, Evans J, Rosenfeld PJ. Age related macular degeneration. BMJ 2010; 340: c981.

39. Limb GA, Daniels JT, Cambrey AD etal. Current prospects for adult stem cell-based therapies in ocular repair and regeneration. Curr Eye Res 2006; 31: 381–90.