CONTEMPORARY APPROACHES TOWARDS EMERGING VISUAL PROSTHESIS TECHNOLOGIES

By

RASHIKA MURUGAN * ATHEENA MILAGI PANDIAN S. ** MOHAMMED SAHIL S. ***

*-*** Atheenapandian Private Limited, Tamil Nadu, India.

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ABSTRACT

Genetic conditions affecting eyesight can lead to vision loss due to a variety of disorders. These include traumatic events such as car accidents or blast injuries, as well as diseases like retinitis pigmentosa, glaucoma, and macular degeneration. After an accident or explosion, the remaining portion of the eye's nerve pathway may still function, allowing electrical devices to transmit significant images to the brain through a network of electrodes. Although current devices offer relatively limited vision, there has been significant progress since the initial proof of concept. Three devices have been approved for general use in various regions around the world, and several more are currently undergoing approval. The prospects for widespread adoption of device-based treatments for vision loss are promising. Much of the recent progress is due to advancements in semiconductors and biological compatibility. To create artificial vision and restore functionality, a camera or other image source electrically stimulates the residual healthy cells or tissues.

Keywords: Retinal Pigmentosa, RP, Vision Prosthesis, Bionic Eye, Nanoretina, Polyretina.

INTRODUCTION

Individuals with Retinitis Pigmentosa (RP) experience permanent damage and destruction of retinal receptors, while individual neurons and internal macular nerve cells tend to be retained. People with RP gradually suffer diminishing vision, particularly in low-light conditions and peripheral vision, resulting in a reduced visual field. As of early 2021, between 82,500 and 11,000 people in the USA have been diagnosed with RP or a similar condition. The manifestation of this condition can vary widely: some individuals endure substantial visual impairment in childhood, while others remain asymptomatic into adolescence (Lim et al., 2020). Many devices use an electrode system, and it is thought that the number of electrodes is directly proportional to enhanced vision restoration. Currently, these devices demonstrate that individuals who are ordinarily blind may perceive motion and detect objects.

1. Literature Review

In a separate study, data were gathered using a questionnaire, and the results showed that 35% of blind patients were unwilling to participate in retinal prosthesis trials, 44% were unsure, and 21% were willing to do so. The top reasons for not participating, in order of frequency, were fear of possible side effects and risks (63%), lack of benefit or potential worsening of condition (58%), poor understanding of information about the trials (47%), financial concerns (32%), and time concerns or inconvenience (26%). Other reasons included a desire for therapeutic benefit (64%), receiving better care (46%), and receiving a treatment better than no treatment at all (36%). Altruism and the desire to receive more information were cited by 27% of respondents each. These observations strongly align with the findings, indicating a universality of views among prospective prosthesis recipients, despite the differences between the two subject groups (Xia in China and Greece).

2. Methods

2.1 Epiretinal Devices

Epiretinal gadgets consist of an exterior and an inserted part. The outside element involves an image sensor, the signal processor's speed, influence, and a signal transceiver. The embedded unit involves several sets of treatment electrodes, a stimulant, and a data and energy receiver. Recorded pictures taken with the camera's sensor are then transformed into electronic data and processed more thoroughly inside the framework in order to create an electrical stimulus that the wires utilize to transfer impulses into the remainder of the undamaged visual tissue. These devices make contact directly with the cells in the ganglion layers. Epiretinal geometries benefit from being somewhat less difficult and maintaining a lesser degree of risk associated with transplantation. As a result, the bulk of studies to produce retinal artificial limbs are centered on epiretinal devices (Bosking et al., 2022; Wang et al., 2023). The NanoRetina 600 (NR600) System is composed of two components. The two main elements are a small embedded gadget and an assortment of eyewear. Goggles are worn to regulate electricity. Implants offer clean images with low distortion for viewing. As shown in Figure 1, the device is physically implanted and utilizes a 3D neural interfacing technique. Its lower ideal energy consumption enhances tolerability and specificity. The implantation process is low risk and has a short recuperation and healing period. The placed device has all the necessary functionality, minimizing the need for excess cabling outside the eye sphere (Erickson-Davis & Korzybska, 2021).

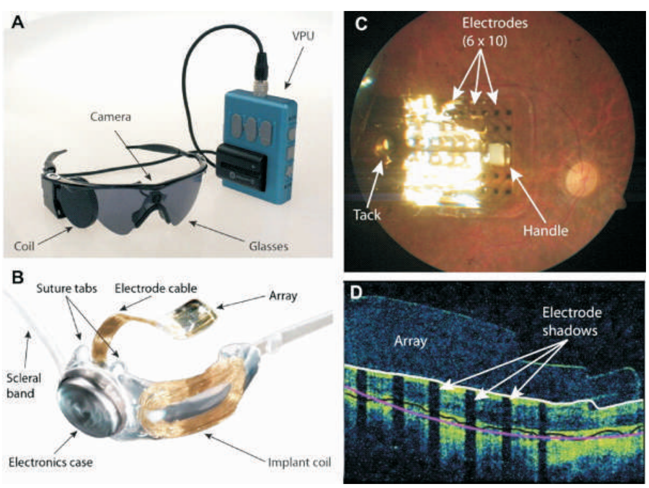

Figure 1. Clinical Results and Future Epiretinal Device Approach

The NR600 has additional wires that are closely spaced, allowing for a high-resolution photograph. The device allows patients to adjust light settings and stimulation levels to meet their specific demands. The investigation started on January 17, 2020, and will continue until June 2023. Trials are currently only available in Italy, Israel, and Belgium, without FDA approval. The internal portion consists of an episcleral electronic implant, a trans-scleral microfabricated cable, and a custom-contoured retinal electrode array with 256 electrodes (Roska & Sahel, 2018).

2.2 Subretinal Devices

The subretinal arrangement incorporates a titanium rod positioned beneath the optic nerve to replace receptors, unlike the epiretinal setup. Sub-retinal architectures benefit from using complete medial retinal processing channels formed by amacrine, vertical, and bipolar cells, despite the ease of endoscopic insertion of epiretinal implantation (Huang et al., 2021). Subretinal implantation, like virtually every other method, is not without risks. The dangers include elevated pressure within the eye, conjunctival injury, and detached retinal hemorrhaging (Palanker et al., 2020).

2.3 Suprachoroidal Prosthesis

Ultimately, the suprachoroidal retinal prosthesis stimulates retinal neurons by being inserted in the scleral pocket for the suprachoroidal-transitional version or between the choroid and sclera (Petoe et al., 2021). The suprachoidal implant's location is intended to avoid ocular injury caused by direct contact. The scleral pocket offers durability, while the choroid blood vessels help to dissipate heat. Furthermore, the newly relocated site makes surgery easier than with prior optical prostheses (Farnum & Pelled, 2020; Mirochnik & Pezaris, 2019). While advantageous in certain ways, the distance above the cornea requires the suprachoroidal prosthetic to vibrate through the higher electrical attraction of the optic pigment epithelium, leading to higher stimulation thresholds that can increase the risk of injury (Borda & Ghezzi, 2022).

3. Clinical Applications

3.1 Lateral Geniculate Nucleus

Information is received from the retina via the optic nerve and forwarded to the cortex of the eye by the lateral geniculate nucleus, which is a visual relay unit situated in the cortex of the brain. The LGN has become a more appealing target for researchers as developments in deep brain stimulation have made surgical access to the thalamus possible. Furthermore, the LGN's compact form permits a large prosthetic visual field, and the overrepresentation of the fovea is thought to allow for higher acuity vision than previous techniques. Additional structural features include the LGN's simple and well-characterized fields of reception as well as its divided visual subdivisions, which may facilitate color artificial vision (Rassia et al., 2022). Full visual field coverage would require two separate arrays, one in each hemisphere, given that the LGN is post optic-chiasm (Huang et al., 2021). Figure 2 shows the responses to demographic questions, including information on gender, age, onset age, education, and community.

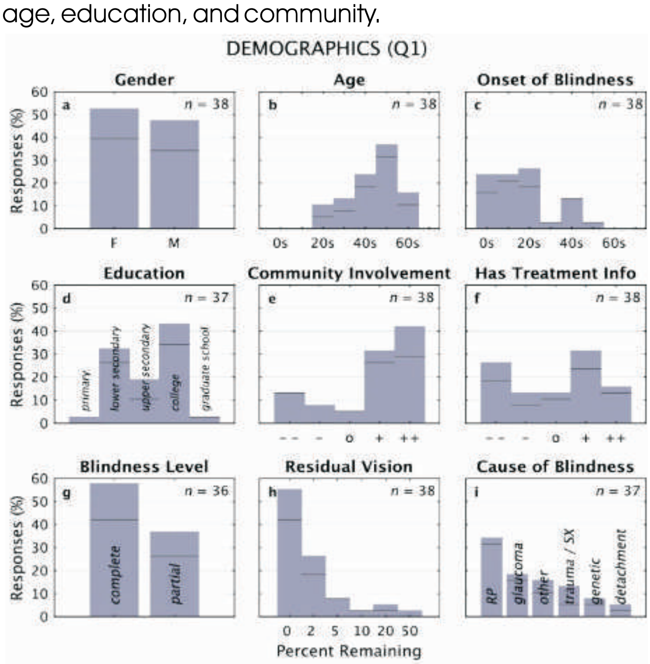

Figure 2. Gender, Age, Onset Age, Education, Community, Info. Responses for demographic questions

3.2 Visual Cortex

It was one of the first areas examined for a visual artificial limb, with Brindley and Lewin's seminal work producing phosphenes in the late 1960s. Furthermore, Dobelle and colleagues developed the first complete ocular prosthesis, the acortical device, about thirty years later. Since then, significant additional attention has focused on the visual cortex due to its large surface area, simple stimulation approach, and applicability to all types of blindness except for cortical damage or stroke (Beauchamp et al., 2020; Chen et al., 2020; Foroushani et al., 2018). The use of penetrating intracortical rather than surface stimulation has allowed researchers to stimulate at much lower current levels than expected while also enabling the use of tightly placed electrodes (Fernández et al., 2021). However, similar to the retina, the cortex may undergo remodeling following blindness, which complicates phosphene mapping. This is analogous to many other prostheses, as shown in Figure 3 (Borda & Ghezzi, 2022; Chen et al., 2020). Instead of using eye movement, the scene camera's head-steering should be employed (Paraskevoudi & Pezaris, 2021). Most recently, Second Sight, developers of the Argus II retinal prosthetic, received conditional FDA approval for clinical trials of the Orion Cerebral Written Prosthesis System (NCT03344848). The Universidad Miguel Hernández de Elche in Spain has begun a clinical study on the CORTIVIS device (NCT02983370), and UCLA is conducting a clinical

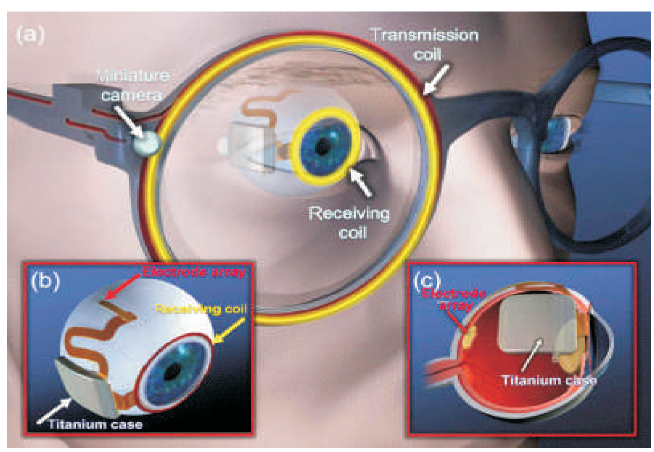

Figure 3. Advanced Techniques Used in Visual Cortex Based Developments

study on the Neuro-Pace RNS System (NCT02747589). Several different groups are developing neural prosthetic devices at various stages (Wang et al., 2023).

3.3 Clinical Trials

A list of the latest clinical studies for optical prosthesis devices are currently registered with the US National Library of Medicine. These initiatives have advanced to the clinical trial stage with their technology. The number of investigators working on devices that have not yet reached the clinical stage is significantly larger, with over two dozen currently known. Note that the list excludes drug-based therapies, as well as non-invasive sensory substitution devices such as BrainPort (Rassia et al., 2018), as previously stated.

4. Discussion

When evaluating the views and desires of blind individuals who might receive vision-restoring technologies, a generally unfavorable environment was discovered, primarily due to the engineering shortcomings of current devices. Opinions were mostly positive regarding the retinal method and negative towards the neural approach, which often involves a pathway from the optic nerve to the thalamus to the cortical area. Attitudes toward potential treatment with a visual prosthetic were significantly influenced by age and years of blindness; those who had been blind earlier in life were more accepting. Concerns about the degree of function recovered, as well as issues of risk and trust, were raised, highlighting that productive interaction between the research team or a doctor and prospective patients is a crucial component of patient recruitment (Chen et al., 2020).

Conclusion and Future Directions

The field of ocular prosthesis has expanded greatly in the last few decades, from proof-of-principle demonstrations that created rudimentary percepts in 1968 to various devices awarded FDA and CE certification for clinical use. Research suggests that many parts of the primary visual pathway, including the retina, the optic nerve, LGN, and visual cortex, are feasible targets for sight restoration. While each strategy has its advantages and challenges, research into the retinal approach has made the most progress. The three distinct techniques of retinal prostheses are epiretinal, sub-retinal, and suprachoroidal, as previously mentioned. The epiretinal technique involves inserting stimulation arrays on the inner limiting membrane, near the retinal ganglion cells, which allows for low electrical thresholds but may result in retinal injury and off-target activation. Devices aimed at various stages of the early pathway have been proven to enhance light detection, character identification, and mobility. However, future research must advance beyond the relatively primitive level of vision provided by existing devices. Specifically, improving the positioning of the prosthesis and further developing the technology would significantly benefit patients. Given that each strategy has its advantages and disadvantages such as suitability for different disease stages and etiologies device selection must be carefully evaluated to best enhance patients' vision. Efforts to address electrode count and spacing, improve visual acuity, expand the visual field area, and optimize size, power limits, and external image processing will enhance the quality of artificial vision for recipients.

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ABOUT THE AUTHORS

Rashika Murugan is the Chief Training Officer for Atheenapandian Private Limited, Tamil Nadu, India, and a Life Member of the Biomedical Engineering Society of India. She completed her Bachelor's degree in the field of Biomedical Engineering. Her research activities are based on Biosignals and Rehabilitation, and she has participated in various national and international conferences worldwide.

Atheena Milagi Pandian is the Founder and Chief Executive Officer of Atheenapandian Private Limited, Tamil Nadu, India. He graduated in Biomedical Engineering in both undergraduation and postgraduation at Anna University (Government of Tamil Nadu) in Chennai, Tamil Nadu, India. He completed his Doctorate at the University of Tango in Thimphu, Bhutan. His research activities are mostly related to Healthcare, with particular interest in the fields of Medical Instrumentation and Prosthetics.

Mohammed Sahil S. serves as a Senior Biomedical Trainer and Head of Operations at the National and International Conferences for the Atheenapandian Organization in Tamil Nadu, India. He specializes in Biomedical Instrumentation, Rehabilitation Engineering, and Virtual Reality.