Chapter 22
Retinal Prostheses

Abstract Severe visual impairment up to the level of blindness is caused by either age-related macular degeneration or retinitis pigmentosa. These are the two usual diseases that lead to degeneration of the outer part of the retina. But even after cellular degeneration in these diseases, i.e., degradation of light-sensing photoreceptors, the remaining visual system of neural networks in the retina may not be damaged in many patients. For such cases, a subretinal implant containing microphotodiodes is placed beneath the retina. Currents produced in the photodiodes by the incoming light energize microelectrodes which stimulate sensory neurons in the retina. Otherwise, an epiretinal implant placed on the surface of the retina is employed along with a video camera. The camera captures the light signal and translates the data into an electrical signal through a microprocessor. This signal is transduced across the nerve cells, through the optic nerve, and eventually to the brain for the conception of an image.

Keywords Retina • Age-related macular degeneration • Retinitis pigmentosa • Subretinal implant • Epiretinal implant • Microphotodiode • Argus II retinal system • Alpha IMS retinal implant

22.1 Introduction

Retinal prosthesis is a groundbreaking medical technology of applying microelectronics to restore partial eyesight to patients whose retina has undergone degeneration. This restoration is done through currents supplied to microelectrodes that are surgically implanted either above or below the surface of the retina [1]. Fortunately, in patients with degenerated photoreceptors of the retina, the nerve cells that carry the signal to the brain often remain intact. As the nerve cells are left unimpaired, it is possible to electrically stimulate them and thereby produce signals that help the patient in image perception. It transpires that 50 % of blindness cases are attributed to retinal damage. Hence, this prosthesis has been the focus of attention. Both private companies and research laboratories are working on it all over the globe.

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22.2 Role of Retina in Vision

Vision is an indispensable ingredient in the quality of life. It brings brightness and color to the world. It also adds manifold dimensions to everything that is circumjacent to us. It is an outstandingly complex form of information processing system. The function of this system depends on an amazing neuroprocessor located at the back of the eyeball. This neuroprocessor is named as the retina [2]. The retina therefore plays a central role in the vision of a person.

For visualization of a picture, the image of an object is formed in the eye and transmitted to the brain. For this image construction and transmission, light has to travel across several layers. "Seeing" is commenced when the light crossing the black opening called the pupil in the center of the iris is concentrated onto the sensory neuroepithelium of the retina by the eye lens. As a result, a reduced, inverted image of the object is projected onto the outermost layer of the retina. This layer is composed of photoreceptor cells, the rods and cones (Fig. 22.1).

The retina is a nerve layer with a complex structure (Fig. 22.2). It comprises ten different layers of cells, including ganglion cells, amacrine cells, bipolar cells, horizontal cells, photoreceptor cells (the rods and cones), and nerve fibers.

The *ganglion cells* represent the first link in the chain of neurons in the retina. Ganglion cells are neurons positioned adjacent to the inward surface of the retina. They gather pictorial information in the form of statistical data in their dendrites from bipolar cells and amacrine cells. The information collected is communicated

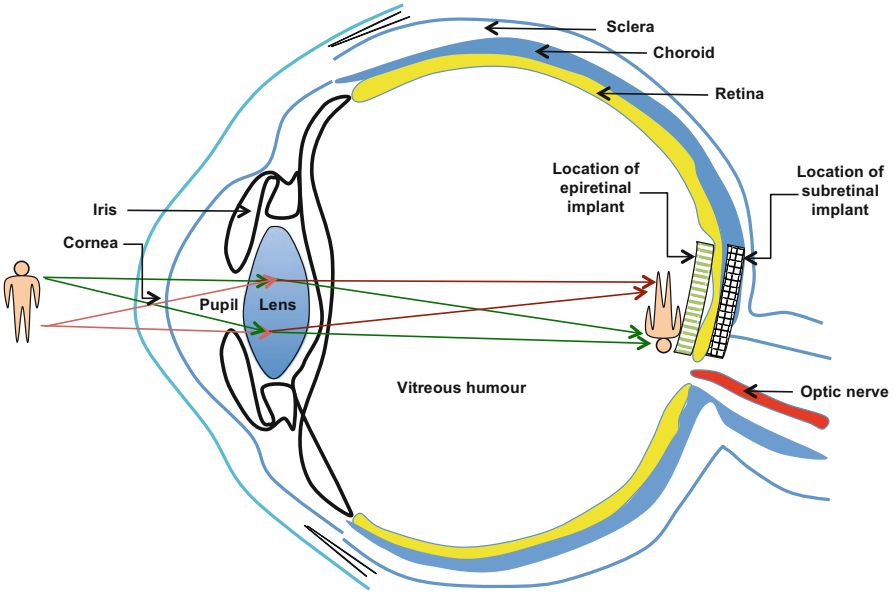

Fig. 22.1 Inverted image construction on the retina. The diagram also shows the locations of epi- and subretinal implants to be described in this chapter

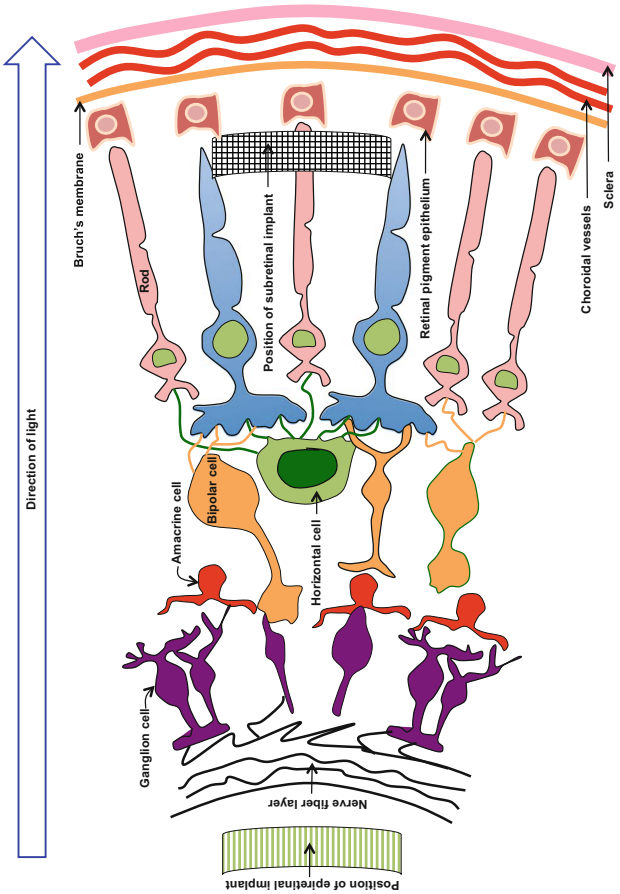

Fig. 22.2 Structure of the retina showing its constituent layers. Also shown are the positions for placement of epiretinal and subretinal implants to be discussed further on

through their axons to the brain. The ganglion cells differ expressively in regard to their dimensions, connections, associations and feedbacks to ophthalmic stimulations.

Amacrine cells are interneurons in the retina. An interneuron is also called a relay neuron. It is a neuron that carries impulses between a sensory and a motor neuron. The amacrine cells are small nerve cells which have dendrites but no axon.

Bipolar cells are signal couriers between the photoreceptors and the ganglion cells. They are so-called because they have two polar extensions protruding from opposite ends of their cell bodies. One extension is towards the photoreceptors and the other towards the ganglion cells for delivery of the processed signal to ganglion cells.

Horizontal cells are the sideways interlocking neurons. They are found in the outer plexiform layer of the retina. Their role is to assimilate/control the inputs received from numerous photoreceptor cells. They allow the eyes to perform adjustments to be able to view correctly, both when the illumination is bright and faint.

The *rods* spread along a much broader extent in the retina. They are used for achromatic vision (without colors). They are necessary for dark-adapted or scotopic vision under low-light conditions. They are also required for peripheral or side vision (seeing objects and motion outside the direct line of vision). They convert the local luminous intensity per unit area and color variations of the image projected on the retina into signals, both chemical and electrical. In dim light conditions, they provide a smaller amount of spatial resolution.

Cones are mainly found in the middle region of the retina, the fovea. They are essential for color vision and high-resolution vision. They generate chromatic or color images of high clarity in the expanse of location of objects, called spatial resolution.

The signals generated by the photoreceptor rods and cones excite the complex circuitry of retinal neurons encompassing the four types mentioned above: horizontal cells, bipolar cells, amacrine cells, and ganglion cells. Gigantic visual information is accumulated from the innumerable photoreceptors of the retina. Hence, it has to be compressed into electrical signals. These signals are transported by highly dedicated ganglion neurons. The axons of these neurons form the optic nerve. By way of the optic nerve, the signals are conveyed to the primary visual cortex of the brain, which processes all the information relating to vision. The signal transmission takes place via a route that passes through the lateral geniculate nucleus.

22.3 Vision Impairment and Its Remedial Schemes

As we understand, the optical pathway for vision is a long journey starting from the eye optics and the lens, then the retina, to the optic nerve, visual cortex, or other cortical areas. These are the multiple regions that diligently carry out the needed signal processing which enables a person to see objects. Destruction or injury to any single step in the above series or chain may cause blindness. About 50 % of all

blindness patients have suffered some form of insufficiency of the retina. In diseases causing blindness, a gradual erosion of the exterior retina takes place. Two such diseases are age-related macular degeneration (ARMD) and retinitis pigmentosa (RP) [3]. The former is a common cause of blindness in the elderly people.

22.3.1 Age-Related Macular Degeneration

As the age of a person advances, the danger of degenerative diseases affecting the retinal cells begins to haunt. For adult patients with age more than 65 years, ARMD stands as the principal reason of vision deprivation in grown-ups. This disease is characterized by loss of cells in the macula close to the center of the retina. Initially, the symptoms observed are the loss of fine vision. These are followed by dwindling central vision with eyes focusing straight ahead, e.g., to drive or read. Eventually, legal blindness may ensue in many patients with central visual acuity measurement of 20/200 or a reduced amount, in superior eye with correction. The central visual acuity is an indicator of sharpness or clarity of vision. Examination of the retinal status of these patients reveals that they can be deprived of as high as 70 % of photoreceptors. Still they may not incur any loss of other types of retinal cells.

22.3.2 Retinitis Pigmentosa

The cardinal basis of hereditary blindness, RP is a genetic disorder that primarily affects photoreceptors in the retina causing incurable blindness. Its symptoms are a reduction in night vision, peripheral vision, and in more acute stages, central vision. Randomized experiments have evidenced that increased vitamin A intake serves to put on the brakes against the symptoms of photoreceptor degeneration. This means that the cells undergo apoptosis (cell death as a normal part of growth of an organism) or necrosis (cell death by disease or injury). However, vitamin A over dosages may harm the liver. RP is accompanied by the exhaustion of up to 0.95 fraction of the photoreceptor layer. Nonetheless, up to 80 % of the inner nuclear layer and ~30 % of the ganglion cell layer are left undamaged.

22.3.3 Evolution of the Concept of Electrical Stimulation of the Retina

Electrical stimulation of the retina and related technological approaches have been attempted to artificially distribute ocular information (in imitation of natural approach) to the outlasting portion of the retina that continues to remain in existence withstanding all the degeneration processes. This has been done as a countermeasure

for restoring at least low-resolution vision to such patients. This vision may be sufficient enough to provide at least light perception and object recognition [4]. During electrical stimulation, the information is transmitted to the brain through neurons in the eye using a series of energized electrodes targeting the retina, which communicates with the visual cortex of the brain. Experimental studies and trials have been conducted on such multielectrode devices called microelectrode arrays containing from only 16 electrodes to >1000 electrodes.

22.4 Two Kinds of Retinal Implant

Presently, research and development efforts are being made on two different varieties of retinal implants [5]: subretinal implants and epiretinal implants. In the first type of retinal prosthesis, namely, the subretinal type, the implant is placed beneath the retina. In the second type, viz., the epiretinal type, the implanted device is lodged on the exterior surface of the retina. Both types of devices rely on the presupposition that even during degeneration of cells in ARMD or RP, the neural network of the retina remains undamaged, i.e., regardless of the non-operation of the light-sensing photoreceptors, the remaining visual system is still functional. While some retinal implant devices are approved, rigorous clinical trials are under way to ascertain the safety, effectiveness, and potential performances of others.

The first approach seems to be more elegant and reminiscent of the actual working of the eye. But it requires implantation of more sophisticated electronics into the eye, increasing the risk of failure of components that are neither easily fixable nor replaceable [6].

22.4.1 Subretinal Implant

As obvious from its name, the subretinal device is implanted underneath the retina. The implant is squeezed between the pigment epithelial layer and the outer layer of the retina. The photoreceptor cells are seated in this outer layer [7]. During surgery for implantation, access must be gained to the subretinal space. This is done ab externo by incision in sclera, the white of the eye. Other surgical procedure is ab interno, which is done through the vitreous cavity and retina. The vitreous cavity is the cavity in the eye which lies posterior to the lens but in front of the retina.

Practically, subretinal prosthetic device for restoring vision consists of a microphotodiode array (Fig. 22.3).

The microphotodiode array contains thousands of small-area, light-sensitive photodiodes, laid out in a well-defined geometrical pattern such that all the photodiodes in the array are equipped with microelectrodes of gold (Au) and titanium nitride (TiN). The complete circuit assembly is fabricated in a compact, low-dimensional footprint on a very thin plate that can be housed in the subretinal space.

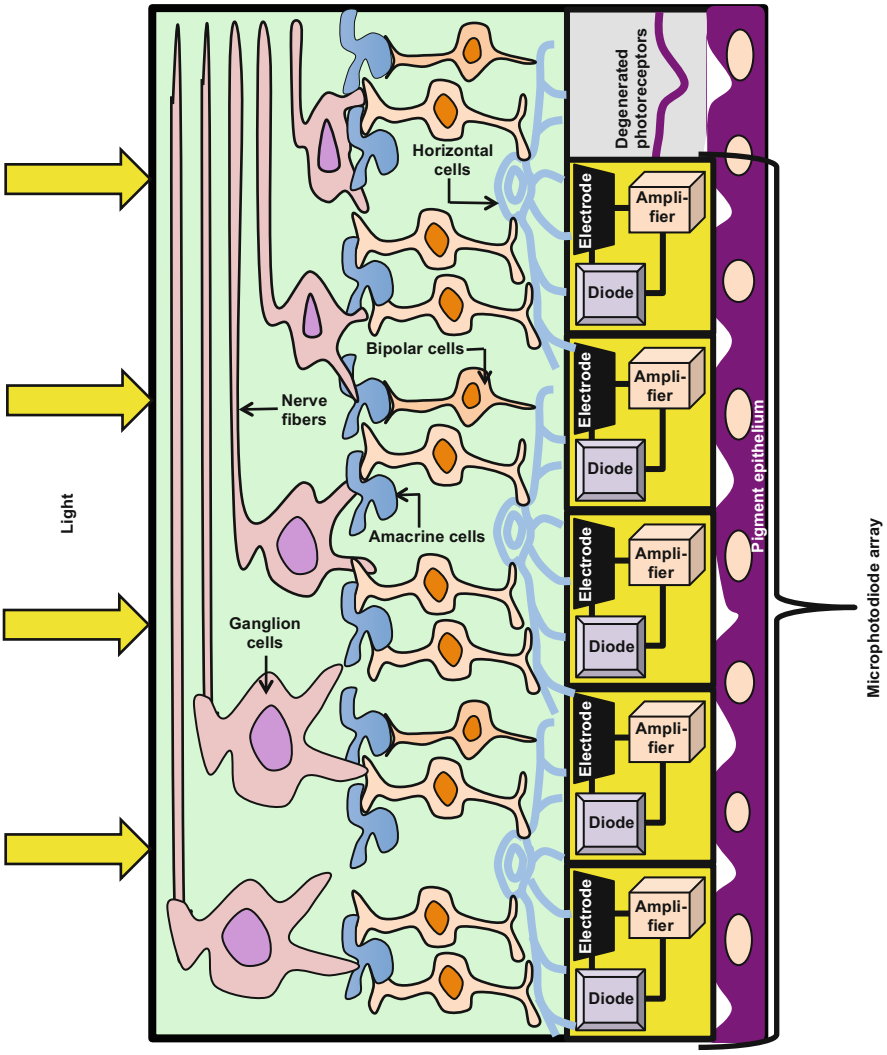

Fig. 22.3 Diagrammatic representation of a subretinal implant

Figure 22.4 shows the construction and working of a silicon photodiode. The photodiode has a P–N–N^+ structure. The P–N junction is a shallow diffused junction. Incident light having energy greater than silicon energy gap is absorbed. It dislodges electrons from the atoms of the crystal lattice creating electron–hole pairs. In zero-bias conditions, the generated electrons and holes drift under the electric field of the depletion region to produce a current flow similar to that obtained in a solar cell. This phenomenon is called the photovoltaic effect. Subretinal implants normally do not use a battery, but application of a reverse bias to a photodiode enlarges the depletion region width and hence increases the effective area in which

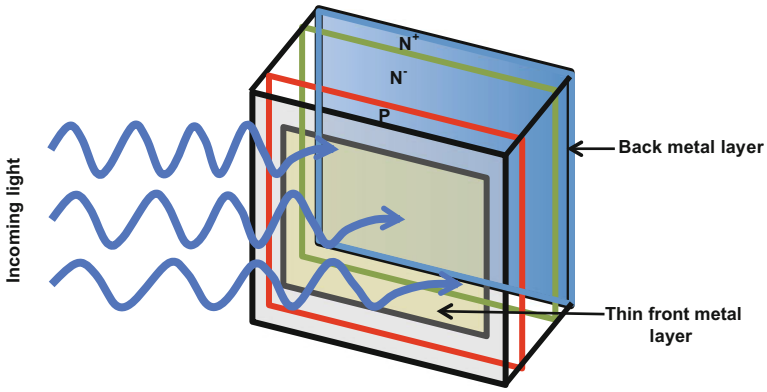

Fig. 22.4 Schematic diagram of a photodiode

electron–hole pair generation effectively contributes to current because the carriers produced far away from the depletion region may be lost by recombination before reaching the depletion region and may not be able to participate in conducting current. Thus, the reverse voltage enhances the sensitivity of the photodiode.

To understand how vision is helped by subretinal implantation, it is necessary to point out that this implant lying between two vital layers, the bipolar cell layer and the retinal pigment epithelium, is essentially meant to substitute the function of photoreceptors. Effectively in the subretinal approach, the place of rods and cones is usurped by a silicon chip carrying a vast number, in the range of thousands, of optically sensitive microphotodiodes, each furnished with a stimulation electrode. Light coming from the image that is incident on the retina modulates the action of microphotodiodes. Currents are produced in the photodiodes in accordance with light variations. The generated currents activate the microelectrodes. Thus triggered by the microphotodiodes, the microelectrodes instill minuscule currents into the residual neural cells left behind, viz., horizontal cells, bipolar cells, amacrine cells, and ganglion cells, of the retinal inner layer. These currents are able to stimulate retinal sensory neurons. Consequently, a visual perception is created in the brain of the patient, representative of the original incident image.

There are many advantages of subretinal prostheses. The microphotodiode array directly replaces the lost or degenerated cells. The remaining cells of the retina are still capable of processing electrical signals and can participate in vision process. Fixing the high density microphotodiode array in the subretinal position is easy. Moreover, there is no need of any external camera or external image processing equipment. Also, eye movement to locate the objects is not restricted.

In principle, a subretinal implant does not require any outside paraphernalia except the microphotodiode array. All the processes, viz., acquisition of light, processing of signals, and stimulation of nerve cells, are carried out by this array. However, a limitation to this implant is that the single microphotodiode array cannot supply adequate current for stimulation. Hence, the implant must be supported by an external energy source, which is included in some versions of this implant. Also, flexible substrates are needed to take care of the delicate nature of the retina and to decrease the light intensity [8].

22.4.2 Epiretinal Implant

There are two main differences between the subretinal and epiretinal implants [9]. Firstly, the epiretinal device is implanted on the surface of the retina and functions with healthy ganglion and bipolar cells. In opposition, the subretinal implant was placed beneath the retina. Secondly, the epiretinal implant has no areas sensitive to light. In contrast, the subretinal approach utilized the light sensitivity of microphotodiodes. Therefore, the epiretinal implant accepts electrical signals from a remote camera and processing unit located outside the body, whereas the subretinal implant received them from the microphotodiode array inside the eye.

In the epiretinal prosthesis, substantial power and data telemetry mechanisms are involved. The typical epiretinal prosthesis system works as a two-component arrangement that consists of an external part attached to the arm of the patient's eyeglasses (Fig. 22.5), consisting of a small video camera, an image processor, and a transmitter coil; and an internal part carrying the decoding circuitry and microelectrode array. The video camera seizes the visual images from the external world. The image processor digitizes the images after reducing their resolution [10, 11]. It transforms the visual images into control signals through a microprocessor. In this manner, the images are transfigured into templates of electrical stimulation. These patterns are fed to the transmitter. Radio-frequency links are used to transfer these signals to the internal part.

The signals are identified and picked up by the internal part. This part consists of a receiver for the relayed information signals and power for the implant. The signals for the microelectrodes are decoded by the integrated circuitry. The obtained spatial and temporal stimulation patterns are used for excitation of the remaining, viable inner retinal neurons that have escaped the onslaught of disease, by controlling the stimulation microelectrode array. Upon stimulation, the electrodes produce action potentials in the upper ganglion cell layers. They directly excite the axons of the inner-layer ganglion cells. These axons form the optic nerve. In this way, the electric signals are transduced across the nerve cells, through the optic nerve, and ultimately to the brain for causing visual sensations and the creation of an image.

Thus, the internal part works by receiving two types of input: (1) statistical information about the visible objects/scenery known as the visual signal and (2) electrical power for feeding the electronics and the electrodes stimulating the retina for generating the visual image akin to the object. The above functions are executed by wireless communication and radio-frequency transmission through a transmitting coil attached to the arm of special glasses; this coil transmits the data and power to the coils kept on the prosthetic device.

Epiretinal implants of various designs have been developed. These designs differ with regard to the implanted and outward components constituting the devices and their operation to facilitate vision. The guiding principle in these designs is to preserve the normal anatomy/physiology of the eye to the maximum extent possible. At the same time, the proportion of implanted electronics required to power the device must be curtailed. In addition, this device must be engineered in such a way that it must exist stably in the saline environment of the vitreous humor without disturbing the rest of the tissue in the eye.

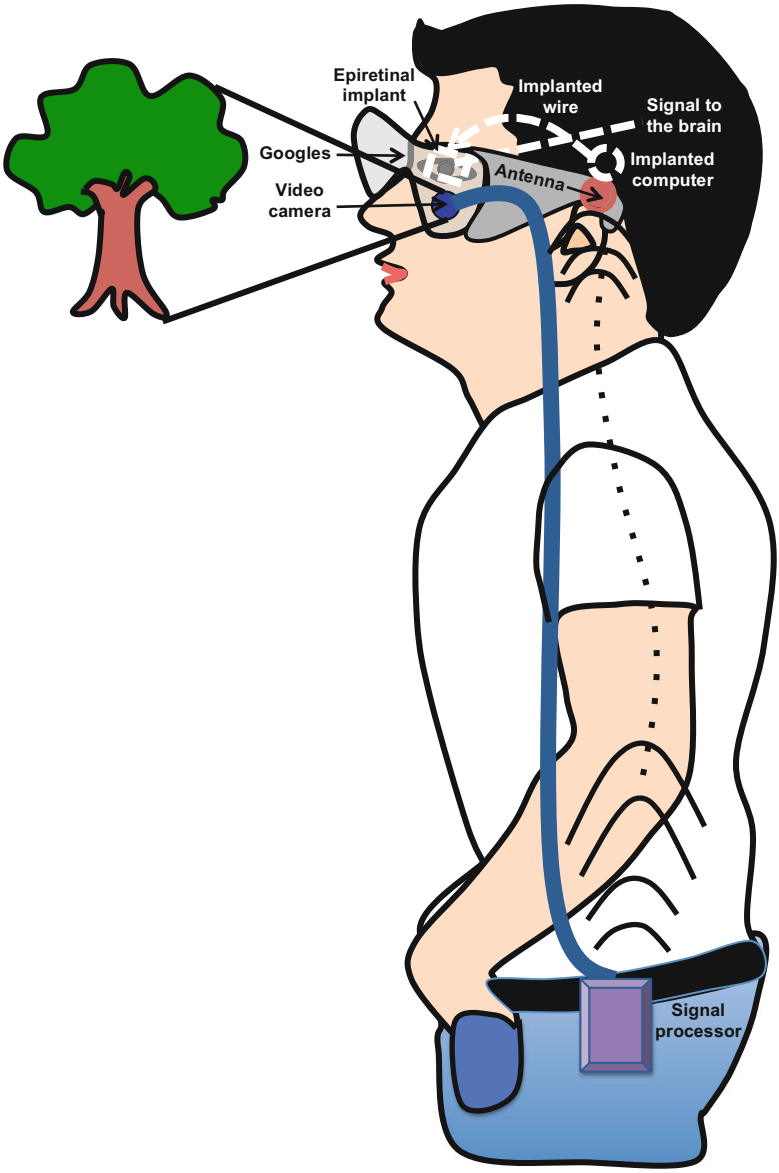

Fig. 22.5 One version of an epiretinal implant in which a video camera in glasses captures the image of an object and sends it to a signal processor from where it is wirelessly transmitted to an antenna over the glasses, then to an implanted microcomputer, and finally to the epiretinal implant which energizes the electrodes to send signals to the brain

In essence, the epiretinal implant is a readout chip. It receives electrical signals containing information about the image from an outlying camera and processing unit. The information-bearing signals are used to generate electrical impulses. The impulses are coupled to the ganglion cells and their axons. Through this coupling, the impulses can propagate via the ganglion cell axons of the optic nerve to the brain.

A comprehensive comparison between subretinal and epiretinal implants is presented in Table 22.1.

22.5 Argus II Retinal System

It is the first retinal implant system designed for adult patients who are aged ≥25 years. This system is meant for patients afflicted with advanced retinitis pigmentosa. These patients could be suffering from plain or no light perception vision. The system consists of three main components. Of these, one component is internal and remaining two components are externally placed [12]. The internal component is a small electronic device working as an epiretinal implant. One external component is a petite video camera fixed to a pair of spectacles of the patient. The other external component is a video processing unit that the patient wears or carries, may be in a pocket [12].

The glasses of the patient together with video camera capture the image of the surroundings. The captured image is in the form of electrical signals. The video processing unit performs signal processing. The processed signals are wirelessly transmitted to the internal component of the system for electrical stimulation of the retina. Upon retinal stimulation, the brain recognizes the image as an array of spots of light. It has been shown by medical studies that the system could help patients in identifying the location or movement of objects and people. It helped them to read large letters, words, or sentences. Moreover, they became more mobile in day-to-day activities. They could detect waysides and walk on footpaths without trudging off. This system was granted approval in Europe in February 2011 and by the FDA in the USA in February 2013.

22.6 Alpha IMS Retinal Implant

After a multicenter clinical trial, European regulatory approval was granted in 2013 to Retina Implant AG, Germany. The company has begun offering its Alpha IMS implant, a subretinal implant. This implant is meant for restoration of moderate sight to RP-blinded people [13]. The system performs the job of the retina from reception of light on a microchip of size 3 × 3 mm. The chip has a resolution of

Table 22.1 Subretinal and epiretinal implants

Sl. No.	Subretinal implant	Epiretinal implant
1.	It is placed behind the retina	It is placed on or above the retina
2.	It sits on the outer surface of the retina. It resides as a layer sandwiched between and touching the photoreceptor layer and the retinal pigment epithelium	It sits inside the retina. It resides adjoining the inner surface of the retina
3.	Its implantation is difficult	Its implantation is easier
4.	Its placement is more clear-cut, as the electrode array for stimulation is positioned directly contiguous to the spoiled photoreceptors	Its mechanical fixation is done using micro-tacking to steady the implant on top of the inner retinal layer
5.	It directly stimulates the photoreceptor layer and depends on the regular processing capability of the retinal layers located on the inner side and in the middle	It directly stimulates the ganglion cells, finding a way around all other retinal layers
6.	It is simpler in design with no external components	It is complex in design with components located internally as well as externally. It works as a two-component device consisting of an extraocular and intraocular part
7.	It allows for normal inner retinal processing, including amplification, by depending on the function of the residual retinal layers. Therefore, when taken as a whole, it requires a smaller threshold to incite a visual response	It requires more sophisticated image processing techniques because stimulation is done at the ganglion cell layer and care has to be taken for the processing that would normally have been done with the bypassed retinal layers
8.	It provides relief to patients having retinal diseases within the photoreceptor layer of the retina	It provides visual discernment to individuals whose retinal infirmity stretches further than the photoreceptor layer
9.	It does not impose the requirement of any external camera or transmitter. Microphotodiodes mounted on a single chip perform all the operations including light acquisition, processing, and stimulation	It entails the use of an external video camera, signal processing chip, and transmitter along with implanted decoding circuit and array of microelectrodes
10.	It enables the patients to move their gaze to locate objects through normal eye movements	It requires patients to make head movements for changing their gaze, as the camera is externally located
11.	Its stimulation is inherently more precise and accurate. This happens because the blueprint of light falling on the microphotodiodes is an undeviating manifestation of the image required	Its stimulation is ill-defined. The stimulation field embraces the ganglion cell bodies but it may overstretch to include close-by axons, related with other areas of the retina. As a result, a slightly imprecise and malformed stimulation pattern is obtained. This pattern ought to be amended by processing electronically

(continued)

Table 22.1 (continued)

Sl. No.	Subretinal implant	Epiretinal implant
12.	Its mounting calls for minimal fixation effort. The underlying reason is that the subretinal space is mechanically held back in position and negative pressure is created by the retinal pigment epithelium within the subretinal space	It is made stable or steadfast by the force exerted by the vitreous humor
13.	It is larger in size but mechanically restricted by the nominal distance separating the outer retina from the retinal pigment epithelium	It allows more miniaturization allowing for a smaller implant because the main portion of electronics is incorporated into the external components
14.	It does not permit upgrading of electronics software/hardware because it is embedded in the eye	It allows simple upgrades to electronics without additional surgery
15.	It does not allow the doctor to have any control over image processing or be able to adapt the processing to different patients	It allows the doctor to exercise complete freedom over processing of images and adaptation of this processing to suit individual patient because of the external electronics
16.	It suffers from higher risk of temperature-induced damage to the retina from heat produced by the implant during operation. This is due to nearness between the implant and the retina	It imposes less risk of thermal damage because the vitreous humor in the vitreous cavity serves as a heat sink and dissipates the warmth produced by the electronic circuits under operation
17.	It does not require external electrical power, but in some cases, the implant may draw power from external segment for enhancement of the image signal	Its external components are battery powered. The implant is supplied power via radio-frequency induction coils
18.	Its performance may be affected due to insufficiency of incident light. As a consequence, the microphotodiodes are unable to spawn tolerable currents. Therefore, often an outside power supply is incorporated in the system for amplifying the effect of available light	It faces no such problem because electronics part lies outside

1500 pixel. The optic nerve is stimulated on the basis of the image seen by the chip. As no external camera is used, viewing around is possible in natural way as one would expect, using the eyes rather than by head movements. Hence, the patient can look around by eye movement, without disturbing the head. The implant is reported to provide a realistic solution to restore purposeful vision. The implant-receiving patients were competent to distinguish numbers on doors, identify faces, and perceive expressions made by face.

A clear advantage offered by the Alpha IMS is that it does not use an external camera [14]. Instead, light detection takes place within the eye. Another exclusive

feature is its higher-resolution framework. Being implanted underneath the retina, it allows the processing of input by the middle layer of the retina before sending the signal to the visual cortex. In a study, functional vision of most of the participants was reinstalled. Some subjects developed substantial visual ability. Postimplantation, a few patients were able to read large printed letters impromptu. These results are supportive and give confidence.

22.7 Optimal Candidates for Retinal Implants

The candidates must be patients affected by ARMD or RP. To qualify as a candidate for receiving a retinal implant, it is essential that at least the ganglion cell layer must be intact, as assessed in a noninvasive manner by a technique known as optical coherence tomography (OCT) imaging. Other vital factors that must be considered when determining suitability of patients include the overall health of the patient and family commitment towards rehabilitation. The latter is no less important for success of the implant.

22.8 Discussion and Conclusions

During the past few decades, treatment of extreme vision impairment by artificial means has reached closer to realization [15]. This research aims to fabricate an implantable medical device that provides helpful vision to those unfortunate sufferers who have exhausted all alternatives. An analogy can be drawn with the cochlear implants used for hearing losses of certain categories. Like cochlear implants, the retinal devices can reestablish useful vision by translating visual information into prototypes of electrical stimulation. These prototypes are used to excite the surviving inner retinal neurons in patients who are grievously affected by ARMD or retinitis pigmentosa.

Although many strides have been taken, the field of artificial vision is comparatively young. Aided by the ongoing progress in microelectronics technology, surgical instruments, and treatment possibilities, there has been a large leap towards restoring partial vision to AMD and RP patients. People who have used this technology have found it to be extremely useful. Compared to the millions of photoreceptors in the normal eye, there are only a small number of electrodes. Yet people can make out a general sense of their surroundings. Partial visual function can be restored to patients with advanced photoreceptor degeneration. This can give them back the possibility of recognizing or localizing objects. They can achieve self-sustained mobility. They can differentiate a cup from a plate. They can know where a door is located in their home. They can tell where a table is placed in the dining room. Some of the missing pieces of information can be filled in by the brain particularly when memory is taken into account.

The various retinal prostheses that have been reported have given many reassurances in limited clinical trials. Each type of prosthesis has distinct advantages and disadvantages. A relevant research topic is the study of likely performance fluctuations of microelectronic chip stuck inside the briny atmosphere prevalent in the eye over an extended period of time. This especially concerns the airtight and waterproof packaging of the micro-fabricated electrode arrays. Research will also need to address the minimization of heat produced by the chip, and its proper dissipation. A paramount biocompatibility issue is raised by the effects that persistent electrical stimulation on the retina can exert and about which not much is known.

Review Exercises

22.1 List the different processes that take place during transmission of an image to the brain? What are the functions of rods and cones in the retina?
22.2 What is the commonest cause of blindness in the elderly people? What kind of blindness arises from inherited reasons?
22.3 Are retinal implants able to correct all forms of blindness? If not, what are the types of blindness amenable to correction within limits by these implants?
22.4 Name the implant, which is placed beneath the retina. Which implant is placed above the surface of the retina?
22.5 How is the function of rods and cones in the eye performed by a subretinal implant?
22.6 Draw the cross-sectional diagram and describe the operation of a microphotodiode.
22.7 Does the epiretinal plant have any light-sensitive region? If not, how does it capture images?
22.8 Which retinal implant has no external components?
22.9 Which retinal implant may not need a battery? Some of the retinal implants may require a battery? What is the function of the battery, if included?
22.10 Which implant is easier to install: subretinal or epiretinal? Explain.
22.11 Which implant is less likely to cause thermal damage to the retina: subretinal or epiretinal? Why?
22.12 Which implant needs a video camera for capturing images: subretinal or epiretinal?
22.13 What are the primary considerations for a candidate's eligibility for undergoing retinal implant surgery?
22.14 Explain the statement, "The epiretinal implant is a readout chip."
22.15 Highlight some research problems in the area of retinal implants.

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