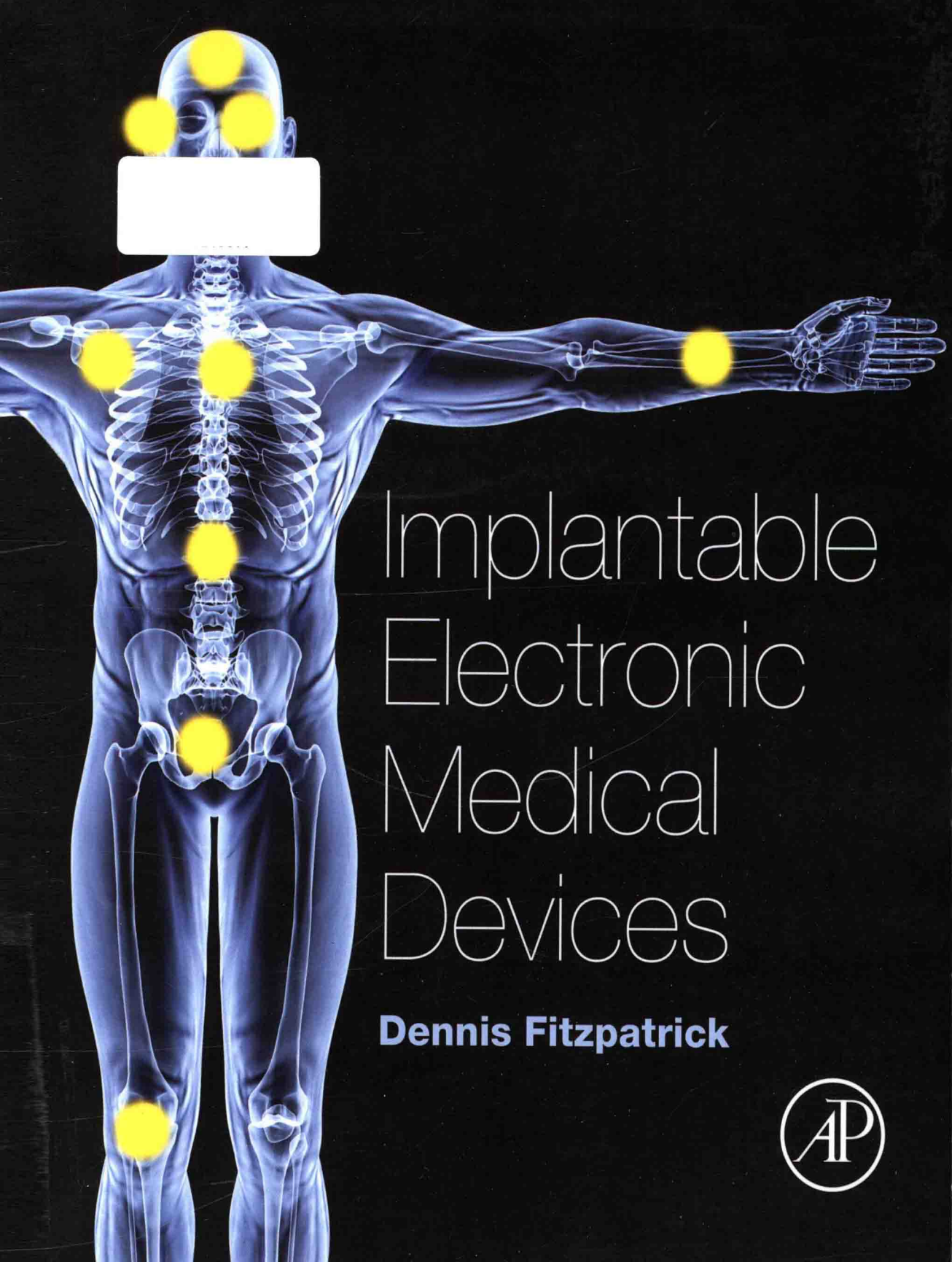


Implantable Electronic Medical Devices

Dennis Fitzpatrick

Implantable Electronic Medical Devices

Dr Dennis Fitzpatrick PhD CEng BEng(Hons)
MIET MIEEE FHEA

ELSEVIER

AMSTERDAM • BOSTON • HEIDELBERG • LONDON
NEW YORK • OXFORD • PARIS • SAN DIEGO
SAN FRANCISCO • SINGAPORE • SYDNEY • TOKYO

Academic Press is an imprint of Elsevier

Academic Press is an imprint of Elsevier
525 B Street, Suite 1800, San Diego, CA 92101-4495, USA
225 Wyman Street, Waltham, MA 02451, USA
The Boulevard, Langford Lane, Kidlington, Oxford OX5 1GB, UK

Notices

Knowledge and best practice in this field are constantly changing. As new research and experience broaden our understanding, changes in research methods, professional practices, or medical treatment may become necessary.

Practitioners and researchers must always rely on their own experience and knowledge in evaluating and using any information, methods, compounds, or experiments described herein. In using such information or methods they should be mindful of their own safety and the safety of others, including parties for whom they have a professional responsibility.

To the fullest extent of the law, neither the Publisher nor the authors, contributors, or editors, assume any liability for any injury and/or damage to persons or property as a matter of products liability, negligence or otherwise, or from any use or operation of any methods, products, instructions, or ideas contained in the material herein.

ISBN: 978-0-12-416556-4

British Library Cataloguing-in-Publication Data
A catalogue record for this book is available from the British Library

Library of Congress Cataloging-in-Publication Data
A catalog record for this book is available from the Library of Congress

For Information on all Academic Press publications
visit our website at http://store.elsevier.com/

Printed in the United States of America

Implantable Electronic Medical Devices

Preface

Implantable systems in the human body are now becoming more widely acceptable and available since the development of pacemakers and other implantable electronic medical devices (IEMDs) such as hearing aids and glucose sensors. With a greater life expectancy and an increasing demand for medical healthcare, there is a greater demand on technology and biomedical engineers to develop implantable systems for a wide variety of medical diagnostics, treatments and therapies. It is fortunate that technology has advanced to complement the realization of IEMDs in terms of miniaturization, complexity, biomaterials and defined standards.

With the new IEMDs comes the introduction of new regulatory standards to bring together national standards from different countries under one internationally agreed standard for the safe design and implementation of IEMDs. Manufacturers will have to comply and show compliance with the new regulatory standard by displaying the new certification marks.

This book collectively groups medical devices with similar functionality into separate chapters. It is the intention of this book to provide a background on the application of medical devices, an introduction to the latest techniques used and examples of existing medical devices. Subsequently, the book can be used as a guide to the design of medical devices and also as a reference for existing medical devices. The book is aimed at those involved in or who have an interest in the research and design of IEMDs. The healthcare industry is vast and includes electronic engineers, bioengineers, biomedical engineers, clinical engineers, clinical scientists, medical practitioners, surgeons and students alike.

Every effort has been made to provide an accurate description of the IEMDs featured in this book. Consequently, I am very grateful to the respective representatives from the medical device manufacturers for their invaluable feedback in order to ensure an accurate representation of their implantable devices. My thanks also go to Laurel Brumant for the anatomical illustrations and to Dr. David Chappell from the University of West London for proofreading and reviewing the chapters in the book. I also thank Barry Nevison for his support on cochlear implants and Tina Lee for her information research. A big thank you also goes to Cari, Fiona and Naomi at Elsevier for their perseverance in chasing up device manufacturers.

DISCLAIMER

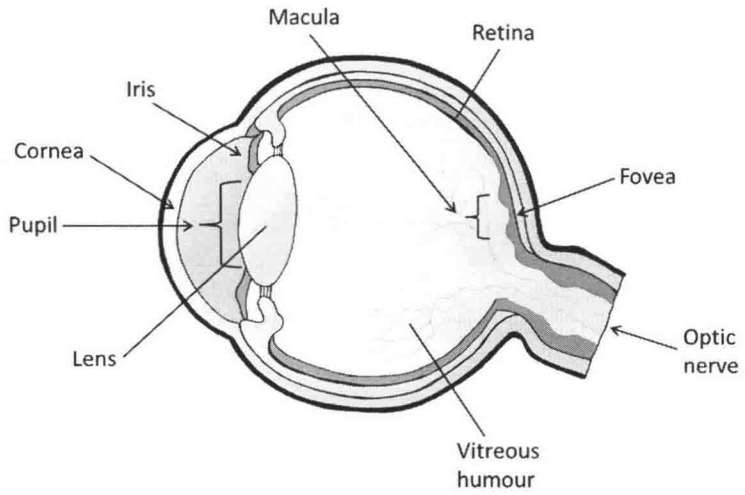
Although every effort has been made by the author to ensure an accurate description of the implantable electronic devices featured in this book, the author cannot be held responsible for any inaccurate representation of the featured IEMDs.

Contents

Chapter 1

Retinal Implants

1.1 INTRODUCTION



■ **FIGURE 1.1** Structure of the eye.

Figure 1.1 shows the main anatomical features of the eye. In normal sight, light enters the eye through the pupil and is focused onto the retina at the back of the eye, stimulating photocells that translate the light into electrical signals. These electrical signals travel down the optic nerve to the visual centers in the brain where they are decoded and perceived as images. Progressive diseases of the eye that result in partial or total loss of vision include glaucoma, retinitis pigmentosa, and macular degeneration.

Glaucoma results from an increase in the internal pressure of the eye, the effects of which are irreversible, eventually leading to loss of sight. However, if detected early, the onset of the disease can be managed with medical treatment or laser surgery. Measuring the intraocular pressure of the eye can help in detecting the early stages of the disease (see Chapter 2).

Implantable Electronic Medical Devices. DOI: http://dx.doi.org/10.1016/B978-0-12-416556-4.00001-2

Retinitis pigmentosa is a genetic disorder resulting in the degeneration of the photoreceptor cells in the retina, leading to partial or complete loss of sight. Currently there is no cure, although gene therapy in which a virus is used to deliver sight-restoring therapeutic genes to the photoreceptors at the back of the eye may offer an alternative form of treatment in the future.

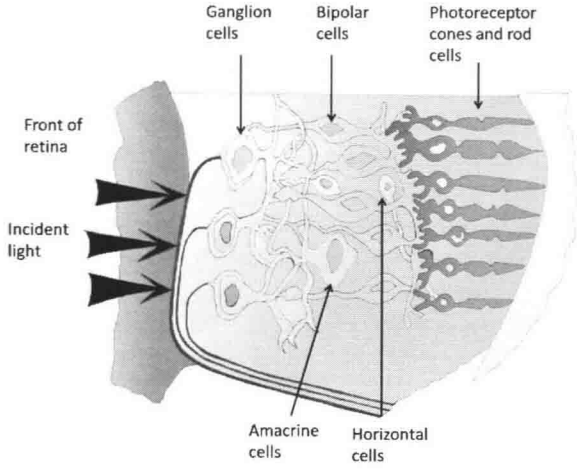
Age-related macular degeneration (AMD) is another disease of the retina, but it only affects a small area of the retina known as the macula which contains a small population of cone-type photoreceptor cells that are more responsive to bright light levels required for reading and viewing objects close up and in greater detail. The onset of AMD occurs in the later stages of life and only leads to a partial degeneration of sight.

Retinal implants are used to help people with degenerative retinal diseases such as retinitis pigmentosa and AMD where the optic nerve and the visual centers in the brain are still functioning but the patient has lost light or sight perception due to degeneration of the outer layer of the retinal photoreceptor cells. However, the cells in the inner retinal layer are relatively intact compared to the outer cells and it is the inner cells which form a neuronal ganglion interface to the optical nerve. Retinal implants will not benefit people who have been blind from birth because their optical visual neuronal circuits and visual processing centers in the brain have not been developed or conditioned to perceive vision.

1.2 THE RETINA

Light entering the eye through the lens is focused onto the retina which consists of a thin layer of transparent neural tissue located at the back of the eye. Near the center of the retina is a region known as the macula which has a high concentration of neural cells responsible for seeing detailed colors and represents the center of vision. At the center of the macula is a small depression or dimple known as the fovea which represents the absolute center of vision and highest color resolution attainable, providing the clearest and sharpest images. Subsequently, the eye continuously moves (saccades) such that the lens focuses images of interest onto the fovea for the highest image of color resolution.

The retina is made up of three main functional neural cell layers: photoreceptor cells, bipolar cells, and ganglion cells. Interspersed between the layers are the horizontal and amacrine neural cells as shown in Figure 1.2. The photoreceptor cells at the back of the retina transduce photon light energy into graded neural signals which are transmitted and processed via the bipolar and ganglion cell layers. It is the axons of the

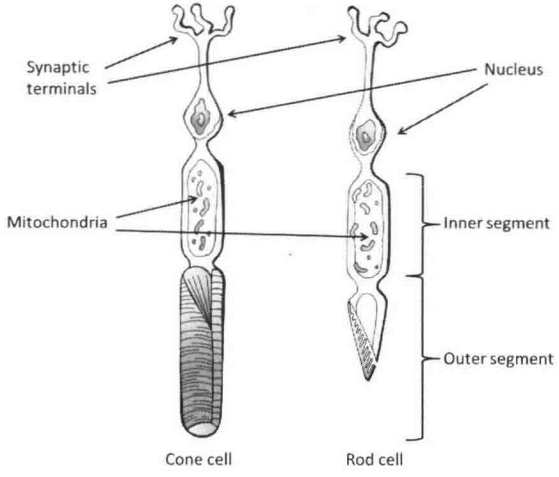


■ **FIGURE 1.2** Structure of the retinal layers.

ganglion cells which together collectively form the optic nerve which leads to the visual processing centers in the brain.

1.3 PHOTORECEPTOR CELLS

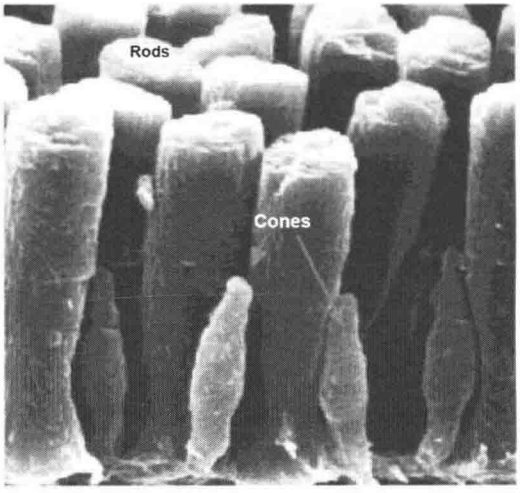
There are two types of photoreceptor cells: rods, which have the ability to detect color but are sensitive to low light levels (scotopic vision), and cones, which in bright light are sensitive to colors (photopic vision) in the visible spectrum. The rods and cones are made up of four segments



■ **FIGURE 1.3** Photoreceptor cone and rod cells.

(Figure 1.3): the outer segment, inner segment, cell body (nucleus), and synaptic terminals.

The outer segment in rods and cones consists of the outer membrane folding in on itself and stacking up to form disks. In the case of rods, the infolded membranes become detached and the disks float inside the outer segment. Located on the disks are light-sensitive pigment proteins, rhodopsin in rods, and iodopsin in cones. The inner segment contains mitochondria which provide the energy required for chemical reactions and the cell body which contains the cell nucleus and other cell organelles essential to maintain cell functionality. The synaptic terminals provide for the transmission of glutamate neurotransmitters between neural cell synaptic bodies.

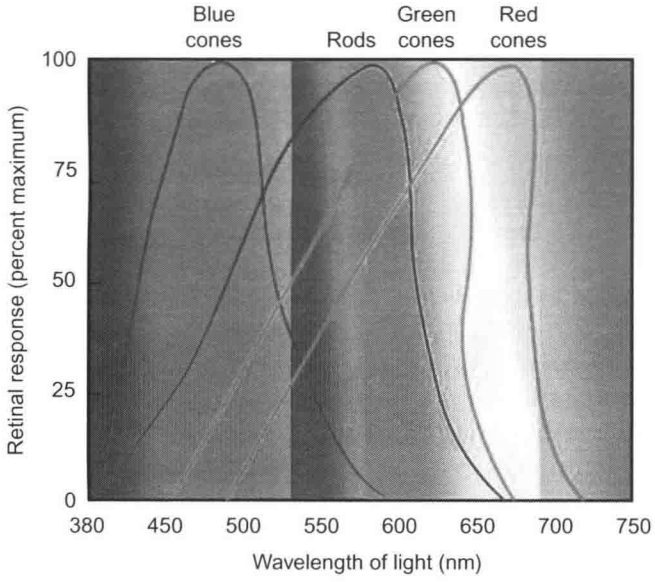


■ **FIGURE 1.4** Structure differences between rods and cones. *(http://www.ic.ucsc.edu/~bruceb/psyc123/Vision123.html.pdf.)*

In rods, the outer segment is cylindrical, whereas for cones, the outer segment is conical in shape (Figure 1.4). Typical outside diameters for the inner and outer segments are 2 μm for rods and 6 μm for cones. The rods also contain a greater number of light-sensitive disks in the outer segment compared to cones, resulting in a greater sensitivity to light. There are typically 120 million rods compared to 6 million cones in the retina.

In rods, all the disks contain the same light-sensitive pigment, rhodopsin, which exhibits a peak absorption of light energy at a wavelength of 500 nm which lies within the blue-green region of the visual light spectrum. In cones, the light-sensitive iodopsin pigment occurs in three

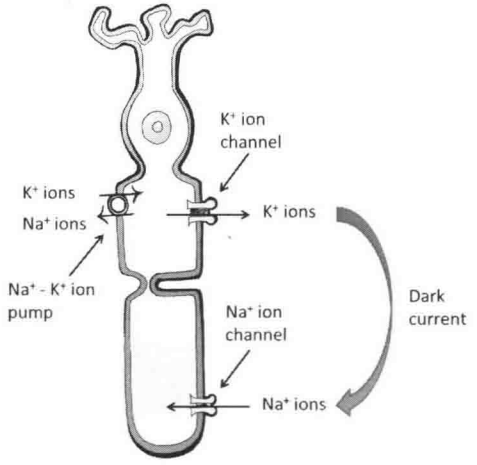
varieties due to differences in their amino acid sequence, each with different peak absorption wavelengths in the red (560 nm), blue (420 nm), and green (530 nm) regions of the visible light spectrum, respectively.



■ **FIGURE 1.5** Electromagnetic spectrum of the human eye.

Although each cone contains three different opsin pigment types, there are three different types of defined cones: short-wave (blue light), medium-wave (green light), and long-wave (red light), each with a predominant opsin variety in the cone. The superimposition of the light absorption response of each opsin pigment will result in a peak response around the area of the defined cone color type. For example, the peak response of a long-wave cone will be shifted due to the superimposition of the individual blue and green opsin spectrum absorption responses, toward the yellow-green region of the visible spectrum as shown in Figure 1.5.

Figure 1.6 shows a rod photoreceptor cell with sodium- and potassium-specific ion channels in the outer membrane. In the absence of light, there will be a continuous flow of positively charged sodium ions into the cell and potassium ions out of the cell, collectively known as the "dark current." This dynamic arrangement gives the photoreceptor cell a resting potential of approximately -30 to -40 mV. Neurotransmitters (glutamate) are also released from the synaptic terminals of the photoreceptor cell. When light photons strike the visual pigments in the disks, a



■ **FIGURE 1.6** Induced ionic currents in photoreceptor cell.

series of chemical reactions involving enzyme activity causes the cell to hyperpolarize and reduce the release of synaptic neurotransmitters.

1.4 BIPOLAR AND GANGLION CELLS

As shown in Figure 1.2, the bipolar and ganglion cell layers are interlaced with two other cell types, the horizontal and amacrine cells. The neural signals from the photoreceptor cells interface with the bipolar cells directly or indirectly via the horizontal cells, which in turn interface with other bipolar cells or other adjacent horizontal cells. Similarly, the bipolar cells interface with the ganglion cells directly or indirectly via the amacrine cells, which in turn interface with other ganglion cells and other adjacent amacrine cells.

There are two types of bipolar cells, both of which receive the glutamate neurotransmitter, but the ON-center bipolar cells will depolarize, whereas the OFF-center bipolar cells will hyperpolarize. This arrangement helps provide a spatial processing of the visual input derived from the photoreceptor cells. The bipolar cells provide one of many sensory inputs to the ganglion cells which are thought to be involved with temporal aspects of color vision being sensitive to speed of movement. The output synapses of the ganglion cells form the optic nerve which transmits the neural image data to the visual cortex in the brain for decoding into perceived images. The ganglion cells also contain the photopigment melanopsin which is involved in the pupillary light reflex mechanism where the pupil constricts when the retina is exposed to bright light.

1.5 RETINAL IMPLANTS

In retinal diseases such as retinitis pigmentosa and AMD where the photoreceptors are damaged, the inner bipolar and ganglion layers are relatively intact and still functioning. Consequently, in order to restore some form of light perception and ultimately vision perception, a retinal implant would need to focus on replicating the sensation of light and darkness by artificially hyperpolarizing and depolarizing remaining photoreceptor and subsequent bipolar cells in a damaged retina.

The technique used by many retinal implantable devices is to stimulate the inner nerve cells of the retina electrically with an ordered pattern of electrical impulses using arrays of electrodes implanted into the retina. The electrical stimuli can then be derived from extracted video data from an external video camera attached to a pair of glasses. Alternatively, microphotodiodes can be used to convert the incident light energy of images on the retina, as the lens of the eye is still functional, into electrical stimuli. The array of microphotodiodes and microelectrodes are symmetrically aligned such that they effectively bypass the outer damaged photoreceptor cells, stimulating the inner nerve cells directly. Retinal prostheses can also provide conditioned electrical impulses to evoke patterns of light dots to represent Braille characters.

Retinal implants can be epiretinal where the implant is inserted on the surface of the retina with electrodes extending into the internal layers of the retina to stimulate either the bipolar or ganglion cells; subretinal where the implant is inserted inside the retina in the photoreceptor layer; or suprachoroidal where implants are implanted in the suprachoroidal space at the back of the eye between the retina and the sclera of the eye.

Other considerations for retinal implants, apart from suitable biocompatible materials, include the mechanism by which the implant is "fixed" in place as well as the technique on how to supply power to the electronic devices in the implant. Typical techniques used include inductively coupled magnetic field coils to transfer energy from an external source to an implanted receiver coil, energy harvesting from the incident light falling on the retina, or using an external infrared laser beam mounted on a pair of glasses to power the implant.

One measure of achieved visual resolution of retinal implants is the visual acuity achieved. Visual acuity refers to the contrast and resolution detail in which an image in the center of vision can be seen. Other terms used include the sharpness, clearness, or acuteness of a perceived image. Visual acuity is measured relative to normal vision, which is defined as