IMAGE FORMATION IN EYE & VISUAL IMPAIRMENTS

BY,

G SUDHANTHIRA
M.E.,

A/P BME

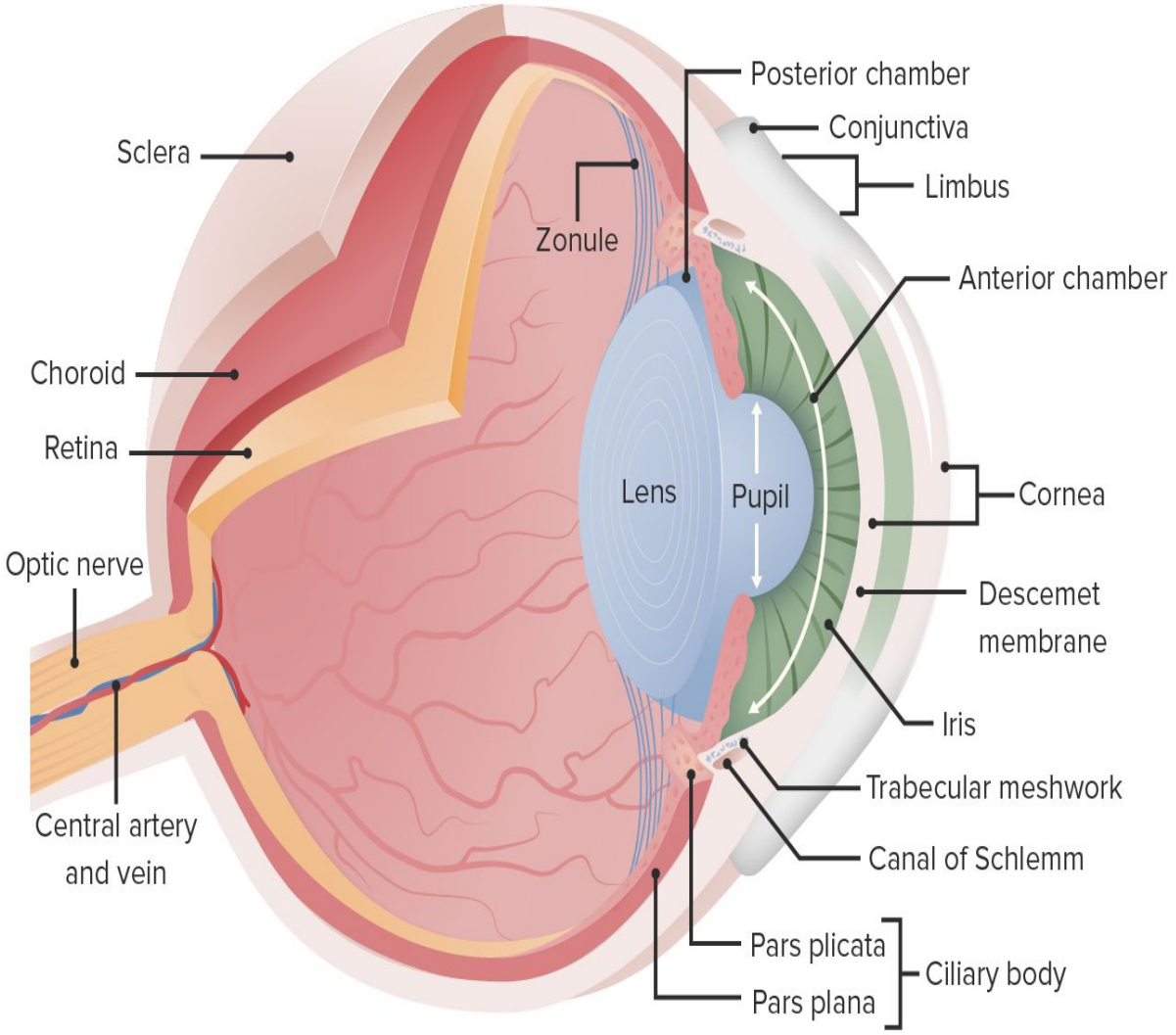
Introduction

- The human eye works much like a camera, with light entering, focusing, and forming an image on the retina, which is then sent to the brain for processing.
- In this presentation, we'll explore how the eye forms images, the anatomy involved, and how different factors can influence image clarity and perception.

- **Objective:** To help the audience understand how vision works at the biological level, including the role of key eye structures in image formation.

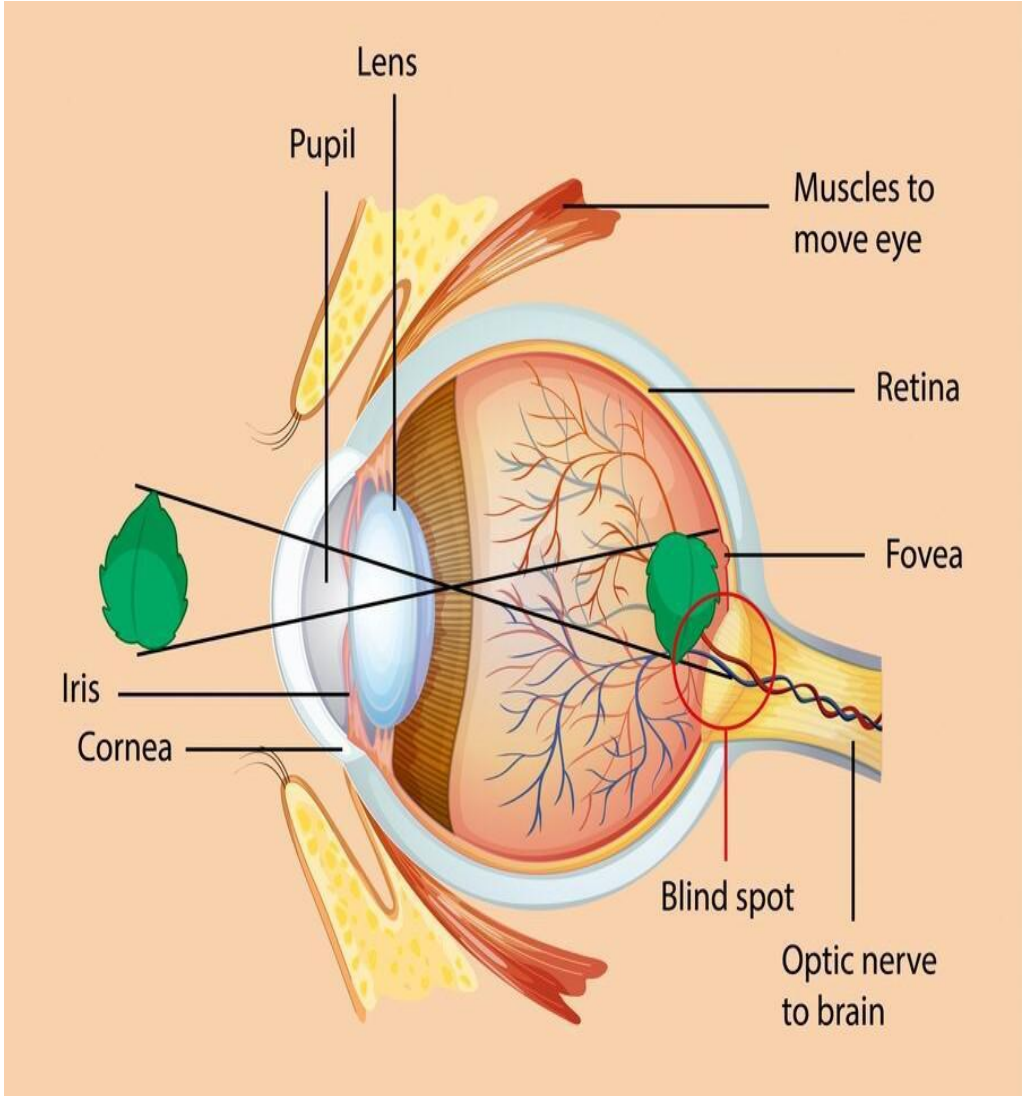
Anatomy of the Eye - Overview

- **Cornea:** The clear, dome-shaped outer surface of the eye, responsible for most of the eye's ability to focus light.
- **Pupil:** The central opening in the iris that allows light to pass into the eye. It adjusts its size depending on light intensity.
- **Lens:** The flexible, transparent structure behind the pupil that further focuses light onto the retina. The lens changes shape to focus on objects at different distances.
- **Retina:** The light-sensitive layer at the back of the eye that captures images and sends them to the brain via the optic nerve.
- **Optic Nerve:** Transmits visual information from the retina to the brain for interpretation.
- **Additional Anatomy:**
  - **Aqueous Humor:** The fluid in the front part of the eye that helps maintain intraocular pressure and provides nutrients to the eye tissues.
  - **Vitreous Humor:** The gel-like substance in the back of the eye that maintains its shape and allows light to travel to the retina.



How Light Enters the Eye

- **Path of Light:**
  - Light first enters the eye through the **cornea**, where it is bent to focus towards the retina. The **cornea** accounts for about 70% of the eye's focusing ability.
  - It passes through the **pupil**, which controls the amount of light entering based on brightness, thanks to the **iris** that adjusts the pupil's size.
  - The light is then further focused by the **lens**, which works to fine-tune the focus.
  - The **retina** receives this light, where it is converted into electrical signals by photoreceptor cells (rods and cones).
  - **Example:** In bright light, the pupil constricts, letting in less light to prevent damage to the retina. In low-light conditions, the pupil dilates to allow more light to reach the retina, aiding vision.



- **Refraction Explained:**
  - Refraction is the bending of light as it passes from one medium to another. In the eye, light refracts as it moves from air into the **cornea** (a dense medium) and again when passing through the **lens**.
  - The **cornea** provides most of the focusing power (around 70%), and the **lens** fine-tunes this focus for near and distant objects.
  - **Law of Refraction:** The degree of refraction depends on the angle at which light enters and the difference in the refractive indices of the two media.
  - **Example:** When you place a straw in a glass of water, it appears bent at the water's surface because light bends as it passes from air to water. Similarly, light bends as it passes through the layers of the eye
- **Cornea’s Function:**
  - The **cornea** is the eye's first point of contact with light and provides the majority of the eye's focusing ability.
  - It acts as a powerful lens that bends incoming light toward the center of the eye. The curvature of the cornea determines how light is focused.
  - **Astigmatism:** If the cornea is irregularly shaped (as in astigmatism), light doesn’t focus uniformly, resulting in blurry vision.
  - **Example:** After a corneal transplant, the vision of a patient with a damaged cornea can be significantly improved because the new cornea restores proper light refraction

- **Pupil’s Function:**
  - The **pupil** is a black circular opening in the center of the iris, and it regulates the amount of light that enters the eye. The iris surrounds the pupil and controls its size.
  - In bright light, the pupil constricts to limit light entry and protect the retina. In low light, it dilates to allow more light in.
  - The pupil’s ability to change size is an automatic response to the intensity of light entering the eye, a phenomenon known as the **pupillary light reflex**.
  - **Example:** When moving from a dark room to a bright outdoor setting, the pupil constricts rapidly to adjust to the bright light, preventing glare.
- **Accommodation Explained:**
  - The **lens** helps focus light precisely on the retina. It is flexible, allowing it to change shape for focusing on objects at varying distances.
  - The **ciliary muscles** surround the lens and adjust its curvature. When focusing on a close object, the muscles contract, making the lens thicker. For distant objects, the lens flattens.
  - **Near-sighted (Myopia)** individuals have a lens that is too powerful, causing light to focus in front of the retina, while **farsighted (Hyperopia)** individuals have a lens that is too weak, causing light to focus behind the retina.
  - **Example:** When you look at a book held close to your eyes, your lens thickens to focus the light properly on the retina. When you look at a distant object, the lens flattens to refocus the light.

- **The Retina’s Role:**
  - The **retina** is a light-sensitive layer located at the back of the eye. It contains two types of photoreceptor cells: **rods** (for low-light vision) and **cones** (for color and detail vision).
  - The image formed on the retina is upside down and reversed due to the properties of light refraction, and the brain later processes this information to correct it.
  - **Fovea:** The center of the retina, where the highest concentration of cones is located. This area is responsible for sharp central vision.
  - **Example:** When you look directly at a bright light source, the light focuses on the fovea, giving you clear and sharp vision of the light.
- **Why the Image is Inverted:**
  - The **lens** inverts the image as it focuses light onto the retina. This is because of the principles of optics: light rays converge and cross over before being focused.
  - The brain then automatically processes this inverted image and flips it back to its correct orientation.
  - **Example:** Similar to a camera, which also forms an inverted image on film, the eye captures an inverted image that the brain later corrects.

- **Focal Length and Image Clarity:**
  - The **focal length** of the lens determines how light is focused on the retina and how clear the image will appear.
  - A **short focal length** allows for a wider field of vision, focusing on nearby objects. A **long focal length** helps bring distant objects into sharper focus.
  - **Example:** A camera lens with a short focal length allows you to capture wide-angle images, while a long focal length zooms in on distant subjects.
- **Role of the Optic Nerve:**
  - The **optic nerve** transmits electrical signals from the retina to the brain's visual cortex, allowing us to perceive visual information.
  - Damage to the optic nerve, such as from glaucoma or optic neuropathy, can result in permanent vision loss.
  - **Example:** When the retina captures an image, it sends electrical signals to the optic nerve, which then carries the information to the brain for processing.

- **How the Brain Interprets Visual Information:**
  - Once the optic nerve transmits signals from the retina, the brain processes them in the **visual cortex** (located in the occipital lobe).
  - The brain flips the inverted image, enhances the details, adds depth perception, and integrates color and motion information.
  - **Example:** When you focus on a face, your brain processes the information, allowing you to identify features and recognize the person.
- **Visual Acuity and Clarity:**
  - Visual acuity refers to the sharpness of vision, typically measured using the **Snellen Chart**.
  - It is affected by the eye's ability to focus light on the retina clearly and accurately.
  - Factors Affecting Visual Acuity- Corneal curvature, lens shape, and retinal health all contribute to visual clarity. - **Example:** If a person has 20/20 vision, they can see objects clearly from 20 feet. A person with 20/40 vision may need to be closer to see the same object clearly.

- **Key Characteristics of the Image Formed on the Retina**
  - **Real** (actual convergence of light rays).
  - **Inverted** (flipped upside down).
  - **Diminished** (smaller than the actual object).
  - The brain processes the signals to perceive the image as upright and at its actual size.

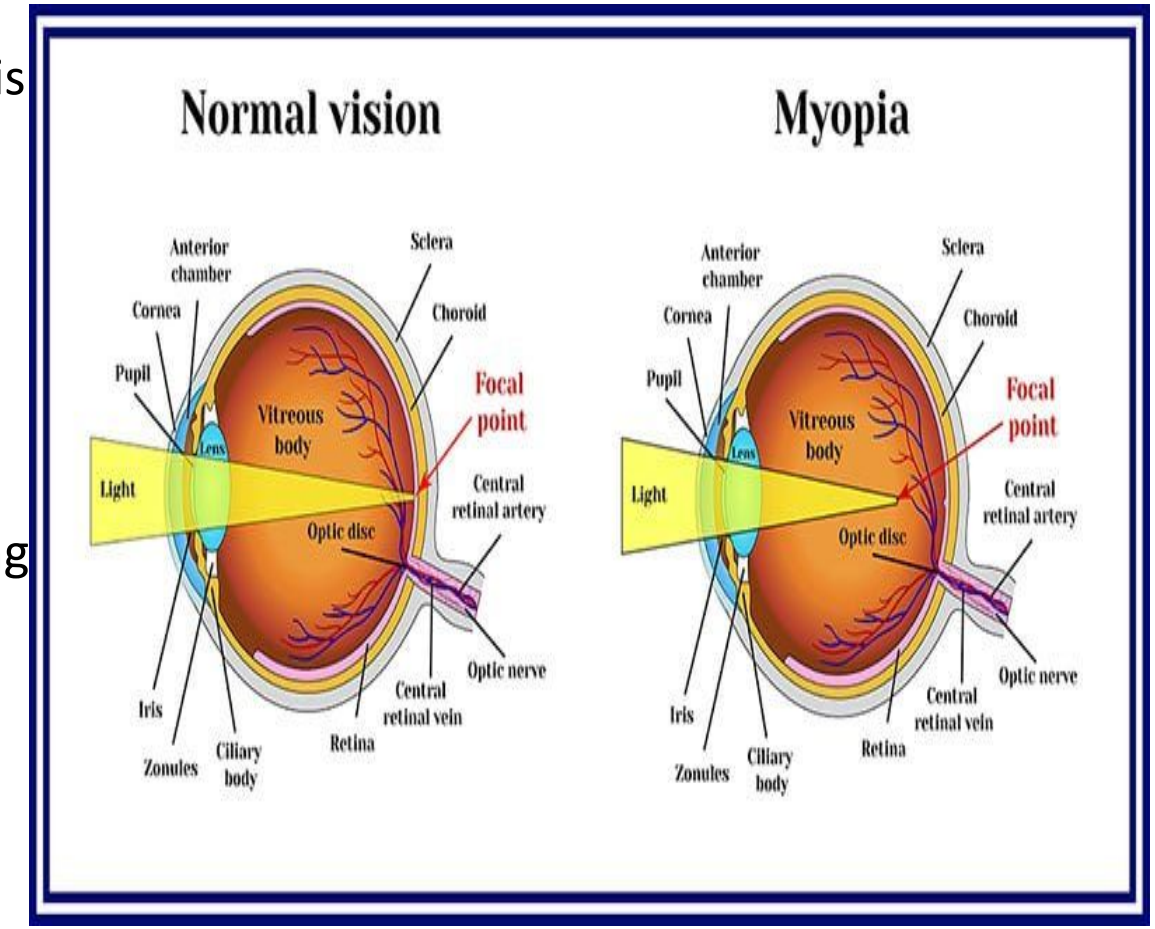
Visual Impairments

- **Refractive Errors:** These occur when the eye cannot properly focus light on the retina, causing blurred vision. Examples include:
  - **Myopia (Nearsightedness)** - Difficulty seeing distant objects clearly.
  - **Hyperopia (Farsightedness)** - Difficulty seeing close objects clearly.
  - **Astigmatism** - Distorted or blurred vision at all distances due to an irregularly shaped cornea or lens.
  - **Presbyopia** - The age-related decline in the ability to focus on near objects.
- **Other Impairments:**
  - **Cataracts:** Clouding of the lens leads to blurry vision, usually in older individuals.
  - **Glaucoma:** Increased pressure in the eye damages the optic nerve, leading to gradual vision loss.
  - **Macular Degeneration:** Degeneration of the retina, especially the macula, causing loss of central vision.
  - **Diabetic Retinopathy:** Damage to the retina due to diabetes, which can lead to vision loss.
  - **Color Blindness:** Inability to distinguish between certain colors, most commonly red and green.
  - **Retinitis Pigmentosa:** A group of inherited disorders that cause progressive vision loss due to the breakdown of retinal cells.

- **What Causes Refractive Errors:**
  - Refractive errors occur when the shape of the eye prevents light from focusing directly on the retina. The three main causes of refractive errors are:
    - **Eye Shape:** If the eye is too long (myopia) or too short (hyperopia), light cannot focus properly on the retina.
    - **Curvature of the Cornea or Lens:** The cornea or lens can be too steep or too flat, resulting in blurred vision.
    - **Aging:** As we age, the lens hardens, causing presbyopia, a condition in which it becomes difficult to focus on close objects.
- **Impact and Prevalence:**
  - Refractive errors are the most common visual impairments worldwide, affecting a large portion of the population. They can be diagnosed early and are often corrected easily with eyeglasses or contact lenses.

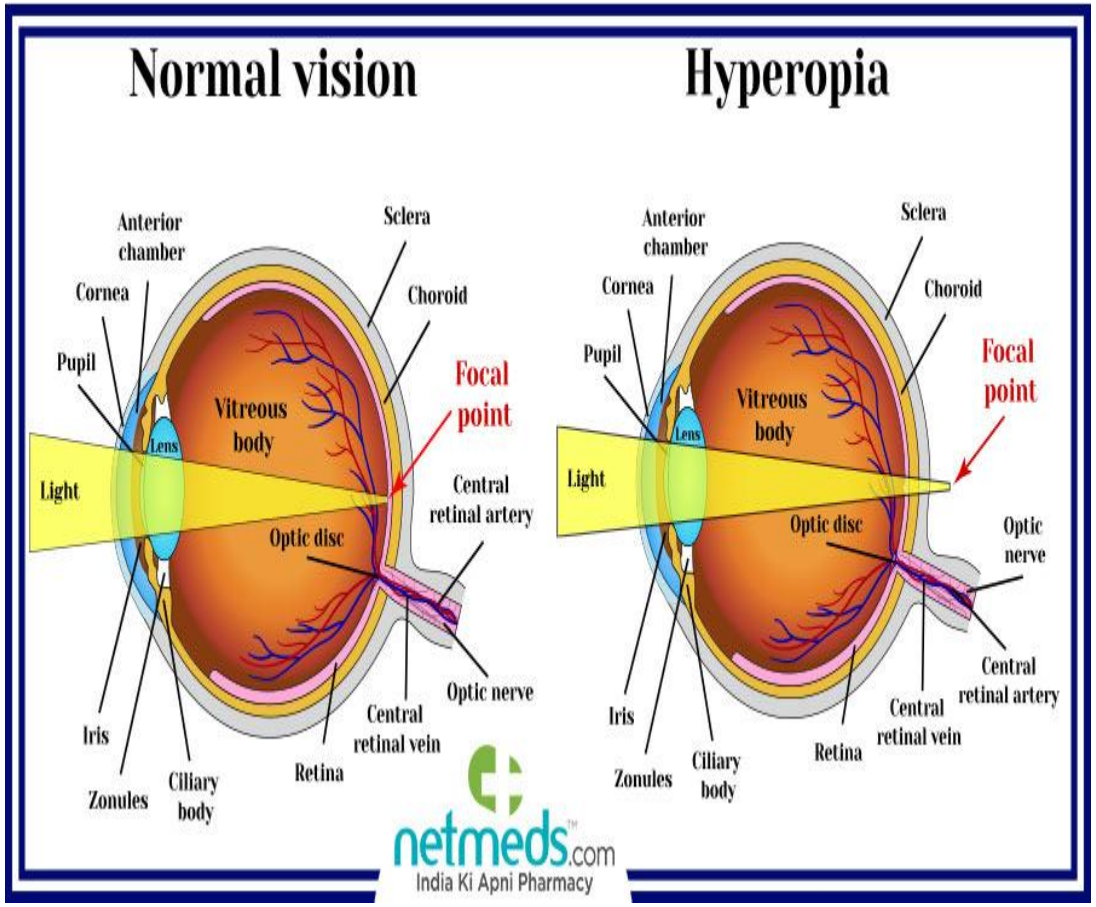
Myopia (Nearsightedness)

- **What is Myopia?**
  - Myopia, or nearsightedness, occurs when the eyeball is too long or the cornea has too much curvature. This results in light focusing in front of the retina, making distant objects appear blurry.
- **Symptoms:**
  - Difficulty seeing faraway objects clearly (e.g., road signs, television screens).
  - Eye strain, especially after prolonged periods of looking at distant objects.
- **Corrective Lenses:**
  - **Concave Lenses** (negative power lenses) are used to diverge the light rays before they enter the eye, allowing the light to focus directly on the retina.
  - Example: A person with myopia would need corrective lenses with a negative diopter value (e.g., -2.00) to bring their vision back into focus.



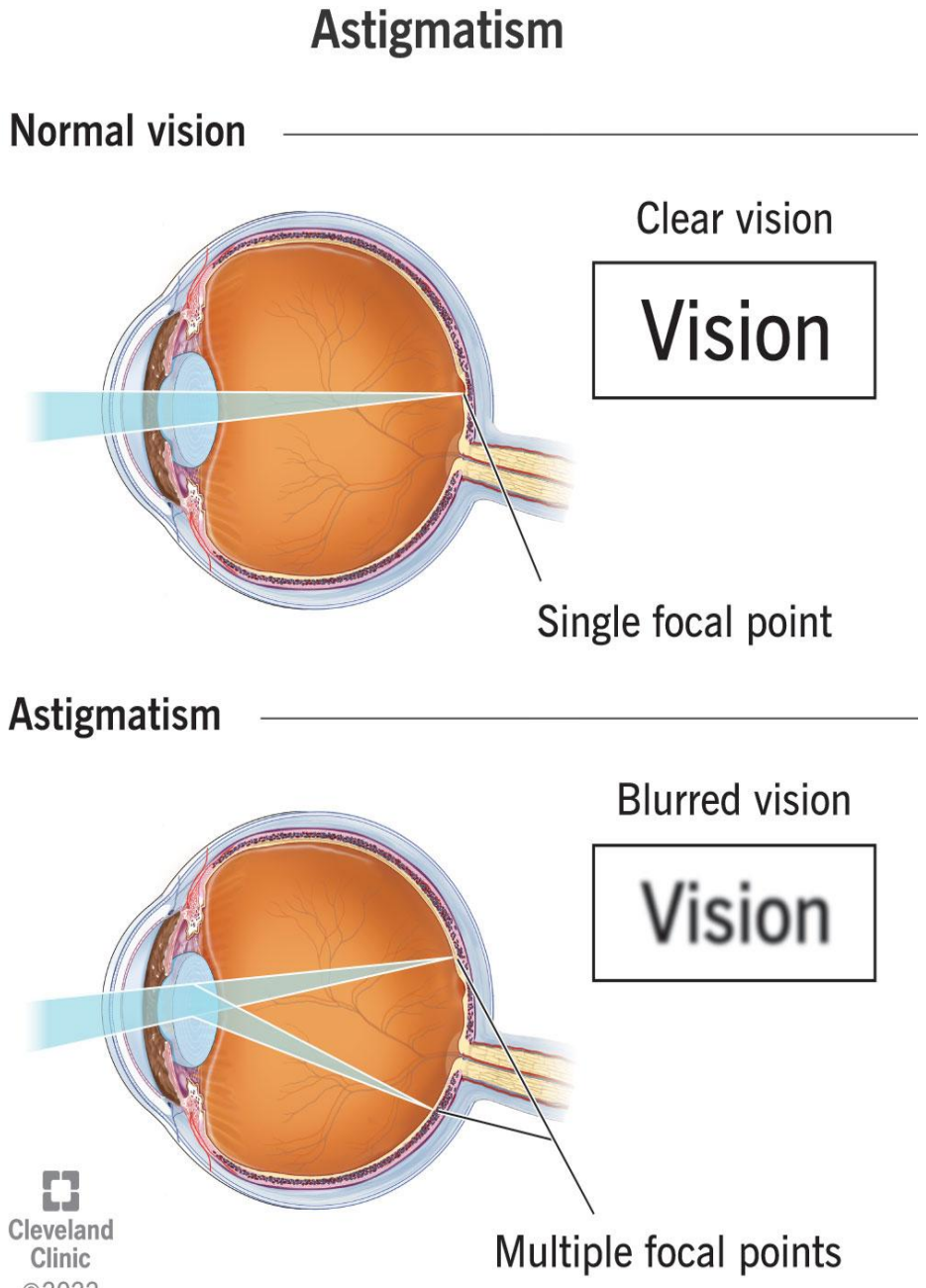
Hyperopia (Farsightedness)

- **What is Hyperopia?**
  - Hyperopia, or farsightedness, occurs when the eyeball is too short, or the cornea has insufficient curvature. This causes light to focus behind the retina, making near objects blurry.
- **Symptoms:**
  - Difficulty reading or doing close-up tasks (e.g., knitting, using a smartphone).
  - Frequent eye strain and headaches when focusing on close objects.
- **Corrective Lenses:**
  - **Convex Lenses** (positive power lenses) are used to converge light rays, allowing them to focus directly on the retina.
  - Example: A person with hyperopia may need glasses with a positive diopter value (e.g., +1.50) to correct their vision.



Astigmatism

- **What is Astigmatism?**
  - Astigmatism is a condition caused by an irregular shape of the cornea or lens, leading to distorted or blurred vision at all distances. The irregularity prevents light from focusing evenly on the retina.
- **Symptoms:**
  - Blurred or distorted vision at all distances.
  - Eye fatigue, headaches, difficulty seeing clearly at night.
- **Corrective Lenses:**
  - **Cylindrical Lenses** are used to compensate for the asymmetry of the eye, allowing light to focus properly on the retina.
  - Example: People with astigmatism may wear eyeglasses or contact lenses specifically designed to correct the uneven curvature of their eye.

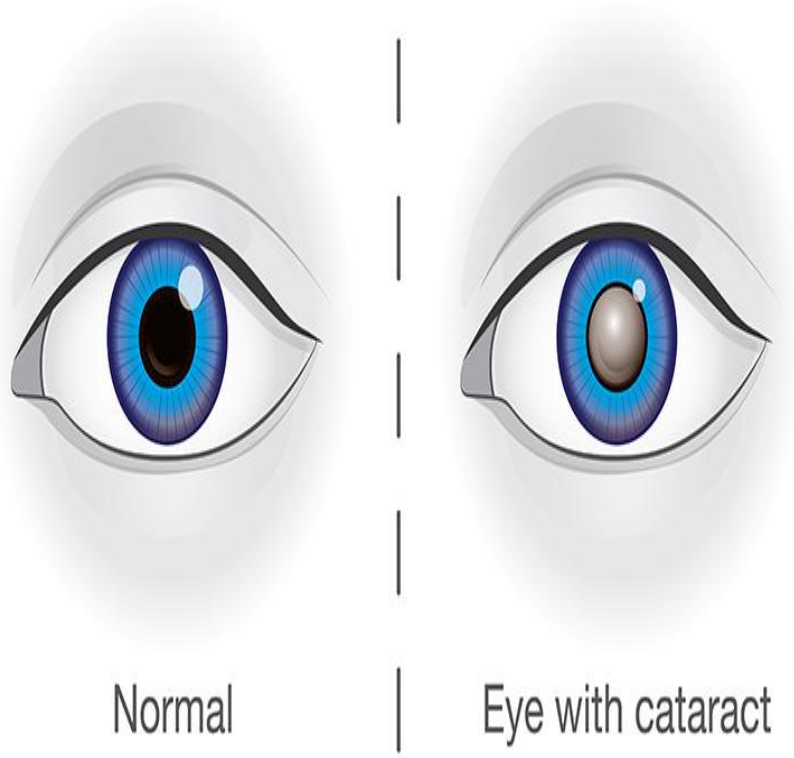


Presbyopia

- **What is Presbyopia?**
  - Presbyopia is the age-related loss of the ability to focus on near objects, typically affecting people over the age of 40. It occurs due to the lens becoming less flexible and harder with age.
- **Symptoms:**
  - Difficulty reading small print, especially in low light.
  - The need to hold reading materials at arm's length.
- **Corrective Lenses:**
  - **Bifocal or Multifocal Lenses** help correct presbyopia by providing different optical powers in different parts of the lens: one for distance vision and one for near vision.
- Example: A bifocal lens will have a distinct separation between the upper (distance) and lower (near) vision zones.

Cataracts

- **What are Cataracts?**
  - Cataracts occur when the natural lens of the eye becomes cloudy, which leads to decreased vision clarity. This condition typically develops with age but can also result from eye injuries or certain medical conditions.
- **Symptoms:**
  - Blurry or cloudy vision.
  - Difficulty seeing at night, glare, and halo effects around lights.
- **Treatment:**
  - Cataract surgery involves removing the cloudy lens and replacing it with an **artificial intraocular lens (IOL)**, restoring clear vision.
  - **Example:** The IOL may be monofocal, accommodating, or multifocal depending on the patient's needs.



Glaucoma

- **What is Glaucoma?**
  - Glaucoma refers to a group of eye diseases that damage the optic nerve, often due to elevated intraocular pressure. The damage to the optic nerve can result in permanent vision loss.
- **Symptoms:**
  - Glaucoma may not show symptoms initially. As it progresses, peripheral vision loss occurs.
  - In the advanced stages, it can lead to tunnel vision or complete blindness.
- **Treatment:**
  - **Medications (eye drops)** are used to lower intraocular pressure.
- **Laser surgery** or **traditional surgery** may be needed for advanced cases to improve drainage and reduce pressure.

Macular Degeneration

- **What is Macular Degeneration?**
  - Age-related macular degeneration (AMD) is a leading cause of vision loss in people over 50, particularly affecting the central vision due to degeneration of the macula (the central part of the retina).
- **Symptoms:**
  - Blurry or distorted central vision.
  - Difficulty reading, driving, or recognizing faces.
- **Treatment:**
  - While there is no cure, **anti-VEGF injections** can slow the progression in wet AMD.
  - **Low-vision aids** may help patients adapt to the changes in their vision.

Diabetic Retinopathy

- **What is Diabetic Retinopathy?**
  - Diabetic retinopathy is a complication of diabetes that affects the blood vessels of the retina. High blood sugar levels over time damage these blood vessels, leading to leakage, bleeding, or complete blockage of the blood vessels.
- **Types:**
  - **Non-proliferative (early stage):** Small areas of leaking blood vessels and swelling in the retina, which may cause blurred vision.
  - **Proliferative (advanced stage):** New, fragile blood vessels grow on the retina, which can bleed and scar the retina, leading to severe vision loss.
- **Symptoms:**
  - Early stages: Often asymptomatic, but as the condition progresses, symptoms may include blurred vision, floaters, and in severe cases, vision loss.
- **Treatment:**
  - **Laser Therapy (Photocoagulation):** Aimed at sealing leaking blood vessels or shrinking abnormal growths.
  - **Anti-VEGF Injections:** These medications inhibit the growth of new, abnormal blood vessels.
- **Vitrectomy:** A surgical procedure to remove blood from the vitreous or to repair the retina.

Color Blindness

- **What is Color Blindness?**
  - Color blindness is a condition where individuals have difficulty distinguishing certain colors. The most common type is **red-green color blindness**, which affects around 8% of men and 0.5% of women of Northern European descent.
- **Causes:**
  - Color blindness is usually genetic, often inherited through the X chromosome. The condition is more common in males.
  - It occurs when one or more of the **cones** in the retina (responsible for detecting color) does not function properly.
- **Symptoms:**
  - Difficulty differentiating between certain colors (e.g., red and green or blue and yellow).
  - Some individuals may not be able to detect color differences at all.
- **Treatment:**
  - **Color Corrective Lenses:** Special lenses or filters can help enhance color contrast and make certain colors more distinguishable.
  - **No Cure:** Currently, there is no cure for color blindness, but there are aids that help people adapt to daily tasks.

Retinitis Pigmentosa

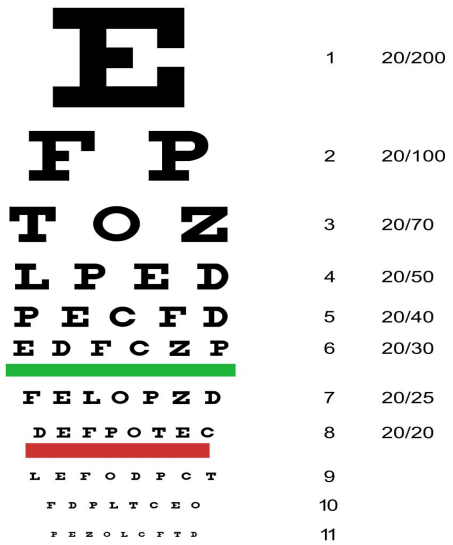
- **What is Retinitis Pigmentosa?**
  - Retinitis pigmentosa (RP) is a group of inherited eye diseases that cause progressive damage to the retina, particularly the **rod cells**, leading to vision loss. It is a leading cause of inherited blindness.
- **Symptoms:**
  - **Night blindness**: Difficulty seeing in low-light conditions.
  - **Tunnel vision**: A gradual narrowing of the visual field.
  - As the disease progresses, it may lead to **complete vision loss**.
- **Causes:**
  - RP is caused by mutations in genes that control the function of the photoreceptor cells (rods and cones) in the retina. The condition is inherited in various patterns (autosomal dominant, recessive, or X-linked).
- **Treatment:**
  - **No cure** for RP exists, but research into gene therapy, retinal implants, and retinal prosthetics holds promise for slowing progression and offering partial restoration of vision.
  - **Low-vision aids**: Magnifiers, text-to-speech devices, and other adaptive technologies help those with severe vision loss.

Assessment and Diagnosis of Visual Impairments

- **Comprehensive Eye Exam:**
  - **Visual Acuity Tests (Snellen Chart):** This is the classic eye chart test where the patient is asked to read letters from a distance. The smallest line of letters that can be seen clearly is used to measure visual acuity (e.g., 20/20 vision).
  - **Refraction Test:** Determines the correct prescription for eyeglasses or contact lenses by using a phoropter and lenses to measure how the eye responds to different light refracts.
  - **Tonometry:** This test measures intraocular pressure to assess for glaucoma. It uses a small puff of air or a device that lightly touches the cornea.
  - **Retinal Examination (Ophthalmoscopy):** The doctor examines the retina for signs of disease, such as damage from diabetic retinopathy, glaucoma, or macular degeneration.
  - **Visual Field Test:** This assesses the full horizontal and vertical range of vision, identifying areas where vision may be lost due to conditions like glaucoma or neurological damage.
- **Advanced Imaging Techniques:**
  - **Optical Coherence Tomography (OCT):** A non-invasive imaging technique that provides detailed cross-sectional images of the retina, which is useful in diagnosing macular degeneration, diabetic retinopathy, and glaucoma.
  - **Fundus Photography:** This photographic imaging technique provides a permanent record of the retina's condition to detect changes over time.
  - **Fluorescein Angiography:** A test where a special dye is injected into the bloodstream and tracked as it flows through the blood vessels in the retina, helping to identify any leaks or blockages.

Comprehensive Eye Exam:

Snellen chart



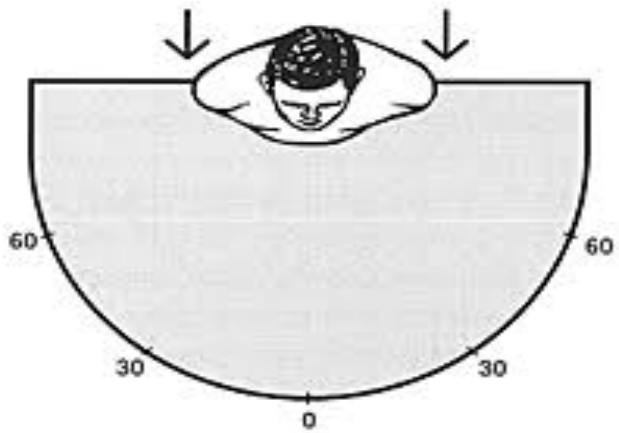
Refraction Test

Tonometry

ADAM

Ophthalmoscopy

Visual Field Test

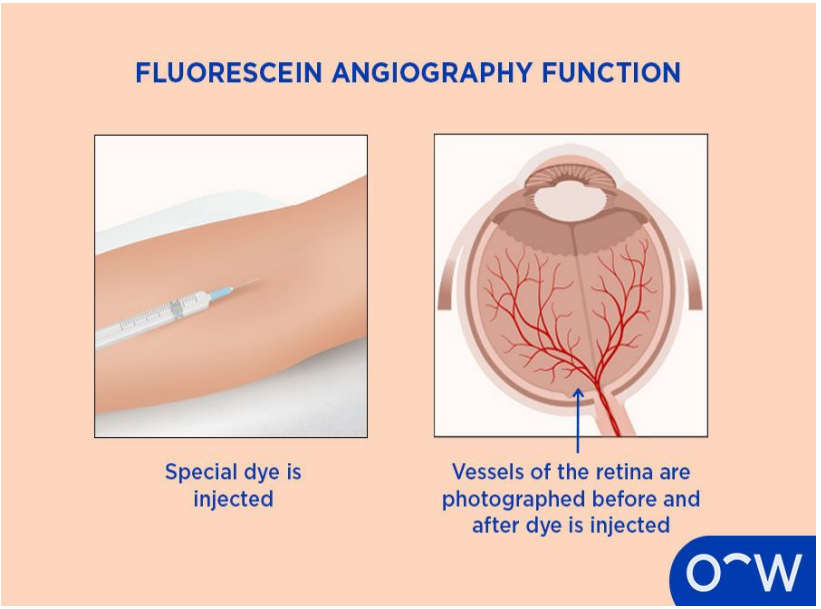


- **Advanced Imaging Techniques:**

Optical Coherence Tomography

Fundus Photography

Fluorescein Angiography



Corrective Lenses and Treatments

- **Eyeglasses:**
  - Eyeglasses are the most common and simplest method of correcting refractive errors. There are different types of lenses to meet :
    - **Single Vision Lenses:** Corrects one field of vision (either near or far).
    - **Bifocal Lenses:** These have two distinct regions (one for near vision and one for far vision).
    - **Trifocal Lenses:** These provide three zones (near, intermediate, and far vision).
    - **Progressive Lenses:** These offer a gradual transition between different lens powers and no visible lines between the zones.
  - **Lens Materials:**
    - **Glass:** Offers optical clarity but is heavier and prone to breaking.
    - **Plastic/Polycarbonate:** Lighter and impact-resistant.
    - **High-Index Lenses:** Thinner and lighter, often used for people with strong prescriptions.
- **Contact Lenses:**
  - Contact lenses are a popular alternative to glasses and are available in various types:
    - **Soft Contact Lenses:** Comfortable and flexible, suitable for daily or extended wear.
    - **Rigid Gas Permeable (RGP) Lenses:** Offer clearer vision and are more durable than soft lenses but may take time to adjust to.
    - **Toric Lenses:** Specifically designed to correct astigmatism.
    - **Multifocal Lenses:** Lenses that correct both near and far vision, similar to bifocals.
- **Surgical Interventions:**
  - **LASIK (Laser-Assisted In Situ Keratomileusis):** A popular procedure to treat myopia, hyperopia, and astigmatism by reshaping the cornea using a laser.
  - **Cataract Surgery:** Removal of the cloudy natural lens and replacement with an artificial intraocular lens (IOL).
  - **Corneal Transplant:** For patients with damaged or diseased corneas, this surgery can restore vision.

Importance of Early Detection

- **Prevention of Further Vision Loss:**
  - Early detection of conditions like glaucoma, diabetic retinopathy, and macular degeneration allows for more effective treatment and can significantly slow or prevent vision loss.
  - **Routine Eye Exams** are especially critical for those at higher risk (e.g., people over 40, diabetics, or those with a family history of eye diseases).
- **Impact on Quality of Life:**
  - Regular eye care ensures the continued ability to perform daily activities safely (e.g., driving, reading, and working).
  - Treating and correcting visual impairments can help avoid accidents, falls, and social isolation.

Emerging Technologies in Visual Impairment Treatment

- **Gene Therapy:** Research in gene therapy holds promise for treating inherited eye conditions like retinitis pigmentosa. This involves modifying genes to correct defective photoreceptor cells.
- **Retinal Implants and Prosthetics:** Retinal implants, such as the **Argus II**, can restore partial vision for individuals with severe retinal degeneration by bypassing damaged cells and stimulating the retina with electrical impulses.
- **Smart Glasses and Low Vision Aids:** Devices like **OrCam MyEye** use AI to read text, recognize faces, and describe objects for people with low vision. Other smart glasses provide magnification or visual enhancement to improve daily living.
- **Bionic Eyes:** These experimental devices involve implanting small sensors in the eye or brain, directly sending visual information to the brain. While in its early stages, this technology could one day offer hope for restoring vision to those who are blind.