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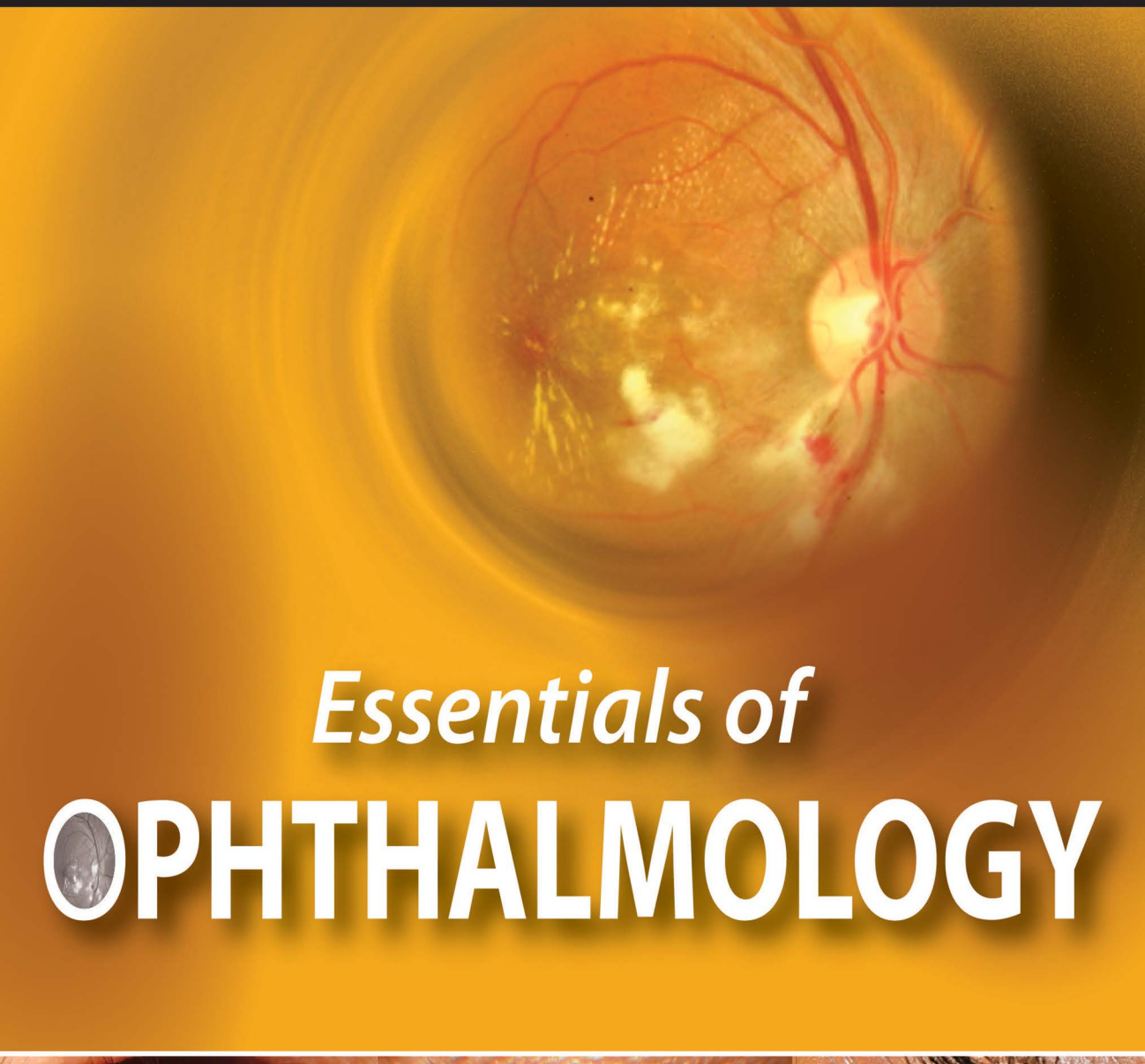

Essentials of OPHTHALMOLOGY



Dadapeer K

JAYPEE

Forewords
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CHAPTER

4.1 Optics of Human Eye

OPTICS

Optics is a branch of physics and involves the study of light.

Light/Visible light is the portion of the electromagnetic spectrum, which is visible to the human eye. It ranges from 390 to 750 nm. Visible light includes seven spectrums of colors ranging from violet to red situated between 390 and 750 nm wavelengths. The portion of the electromagnetic spectrum below violet is called ultraviolet (UV) light and the portion above is called infrared light.

Ultraviolet light is the portion of the electromagnetic spectrum with wavelength shorter than visible light ranging from 10 to 390 nm. The UV light is invisible to the human eye. Most of the UV light is blocked by the ozone layer of the atmosphere. The UV light is necessary for production of vitamin D. Long-term exposure to the UV light is implicated in many conditions of the eyes such as cataract, pterygium, skin cancers, etc.

Infrared light is the portion of the electromagnetic spectrum with wavelength longer than visible light with wavelength more than 750 nm.

Reflection of Light

Reflection of light is the phenomenon of turning back of light into the same medium after striking the boundary of other medium.

The boundary between the two media is called reflective surface, the light rays falling on the reflective surface are called incident rays and the rays reflected back from the reflective surface are called reflected rays.

Laws of Reflection (Fig. 4.1.1)

1. The incident rays, reflected rays and normal (a line drawn perpendicular to the reflecting surface between incident rays and reflected rays) all lie in same plane.
2. The angle of incidence (angle between the incident ray and normal) is equal to the angle of reflection (angle between the reflected ray and normal).

Types of Reflection

Reflection is of two types:

1. Regular reflection: It occurs when light rays fall on smooth surfaces (e.g. mirror). Here, the parallel light rays falling on the smooth

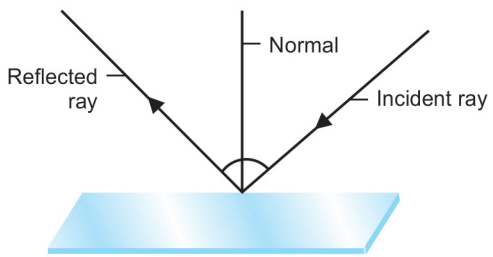


FIG. 4.1.1: Laws of reflection

reflective surface will lead to parallel reflected rays leading to the formation of image.

2. Irregular reflection: It occurs when light rays fall on rough surfaces (e.g. stone). Here, the parallel light rays falling on the smooth reflective surface will lead to divergent reflected rays and thus image is not formed.

Mirror: It is a reflective surface and the light rays falling on it undergo regular reflection. It can be plane mirror or spherical mirror.

Plane mirror

A mirror with plane reflective surface is called plane mirror. The image formed by a plane mirror is virtual, erect, laterally inverted and lies as far behind the mirror as the object is in front of it.

Spherical mirror

A mirror with spherical reflective surface is called spherical mirror. It can be concave spherical mirror or convex spherical mirror depending on the reflecting surface.

Concave spherical mirror

In concave spherical mirror, the inner side of the sphere is used as reflecting surface and it converges the parallel beam of light rays. The image formed by a concave mirror depends on the position of the object:

- Object at infinity forms real, minified, inverted image at principal focus of the mirror
- Object at the center of curvature of the mirror forms inverted and same size image at the center of curvature
- Object at the principal focus of the mirror forms real, magnified and inverted image at the infinity
- Object between the principal focus and pole of the mirror forms virtual, magnified and erect image behind the mirror.

Convex spherical mirror

In convex spherical mirror, the outer side of the sphere is used as reflecting surface and it diverges the parallel beam of light rays. Convex mirror forms virtual, erect and minified image.

Refraction of Light

Refraction of light is the phenomenon of change in the direction of light due to change in the density of transmission medium, when light travels from one medium to another medium.

When light passes from a medium with higher density to a medium with lower density, the light moves away from the midline and when light moves from a medium with lower density to a medium of high density, the light moves toward the midline.

Laws of Refraction (Fig. 4.1.2)

- The incident rays and refracted rays lie on either side of the normal and all lie in the same plane
- The ratio of sine of the angle of incidence and sine of angle of refraction is constant.

This constant is called refractive index, when the light travels from air or vacuum. Refractive index is the ratio of speed of light in vacuum or air to the speed of light in the medium.

LENS

Lens is a transparent refractive medium with two surfaces. Lenses are of two types, spherical lenses and cylindrical lenses.

Spherical lenses are bounded by two surfaces, which form part of a sphere. A spherical lens can be convex spherical lens or concave spherical lens.

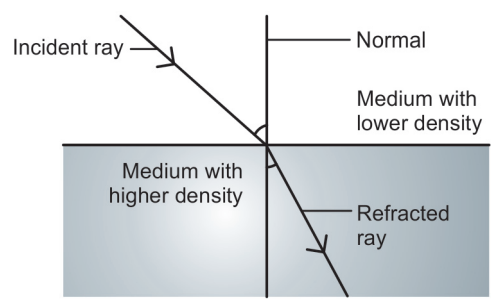


FIG. 4.1.2: Laws of refraction

Cylindrical lenses are bounded by two surfaces, which form part of a cylinder. A cylindrical lens can be convex cylindrical lens or concave cylindrical lens.

The image formation in convex lens depends on the position of the object and it is similar to the image formation in concave mirror. The image formation in concave lens is always virtual, erect and minified, similar to the image formation in convex mirror.

For Ophthalmic lenses refer Author's textbook *'Clinical Methods in Ophthalmology'*, Chapter 7, 'Ophthalmic Lenses'.

Sturm's Conoid (Fig. 4.1.3)*

The Sturm's conoid indicates the path of the light through a toric lens. In toric lens, the two principal meridians are unequal with one median being more curved than the other; hence, the light does not come to a point focus, but forms a line focus with two lines being perpendicular to each other. The best focusing occurs in between these two lines of focus and it is called circle of least confusion. The distance between the two lines of focus is called focal interval of Sturm.

The circle of least confusion indicates that spherical equivalent of the cylindrical lens. This corresponds to a point where the horizontal and vertical dimensions of the image are equal and the goal of a spherical refractive correction is to choose a lens that produces circle of least confusion.

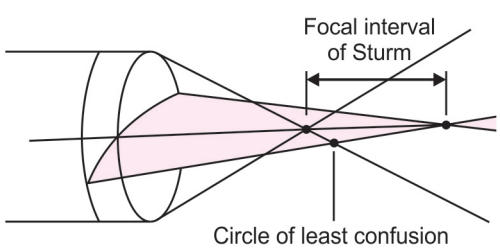


FIG. 4.1.3: Sturm's conoid

OPTICS OF HUMAN EYE

Eye has a compound optical system with two refractive mediums, cornea and lens, which focus the light rays onto the retina.

Schematic Eye*

Allvar Gullstrand has described the schematic eye with two nodal points, two principal points and two principal foci.

Gullstrand's Schematic Eye

- The total refractive power of the eye is +58 D with cornea +43 D and lens +15 D
- The two principal points are situated 1.35 mm (P_1) and 1.60 mm (P_2) behind the anterior surface of cornea respectively
- The two nodal points are situated 7.08 mm (N_1) and 7.33 mm (N_2) behind the anterior surface of cornea respectively
- The two principal foci are situated 15.70 mm (F_1) in front of and 24.38 mm (F_2) behind the cornea, respectively.

Allvar Gullstrand, a Swedish ophthalmologist was awarded Nobel Prize for description of schematic eye. He was the one who invented slit lamp.

Reduced Eye*

The reduced eye model was described to simplify the complex optical system of the eye by considering a single refractive surface.

Listing's Reduced Eye

- The total refractive power of the eye is +60 D
- The principal point is situated 1.5 mm (P) behind the anterior surface of cornea
- The two nodal points are situated 7.2 mm (N) behind the anterior surface of cornea
- The two principal foci are situated 15.70 mm (F_1) in front of and 24.38 mm (F_2) behind the cornea respectively

- The anterior focal length of the eye measuring 17.2 mm and posterior focal length of the eye measuring 22.9 mm.

Donders' Reduced Eye

- The total refractive power of the eye is +60 D
- The principal point is situated 2 mm (P) behind the anterior surface of cornea
- The nodal point is situated 7 mm (N) behind the anterior surface of cornea
- The anterior focal length of the eye is 15 mm and posterior focal length of the eye is 20 mm.

The schematic eye model of the human eye with two principal points and two nodal points is simplified by the reduced eye model with one principal point and one nodal point to simplify the calculations of the size and positions of the images produced by the human eye.

GIST BOX 4.1

- Eye has a compound optical system with two refractive mediums, cornea and lens, which focus the light rays onto the retina.
- The total refractive power of the eye is +60 D.
- The principal point is situated 1.5 mm (P) behind the anterior surface of cornea.
- The two nodal points are situated 7.2 mm (N) behind the anterior surface of cornea.
- The two principal foci are situated 15.70 mm (F_1) in front of and 24.38 mm (F_2) behind the cornea, respectively.
- The anterior focal length of the eye measuring 17.2 mm and posterior focal length of the eye measuring 22.9 mm.

CHAPTER

4.2 Techniques of Refraction

Refraction in eye is defined as a process by which the light rays are focused onto the light-sensitive layer of the retina. Refraction occurs in the eye at the:

1. Cornea, which is the first and the most important refractive surface with refractive power of 44 D accounting for two thirds of the refractive power of the eye.
2. Lens with refractive power of 16 D accounting for rest of the power of the eye.

The refractive power is determined by the curvature of cornea and lens, and index of lens. In emmetropia, the refractive power and axial length are in proportion to each other; hence, the light rays are focused onto the retina.

Emmetropia is determined by:
- Curvature of cornea.
- Curvature, position and index of lens.
- Axial length.

Any abnormality in any one of the above factors will lead to emmetropia.

The techniques of determining the refractive status of the eye and correcting the refractive errors are included under refraction. The techniques of refraction are broadly classified into two types.

TYPES OF REFRACTION

1. Objective refraction: It is done without active participation of the patient.
2. Subjective refraction: It is done by participation of the subject or the patient.

TECHNIQUES OF OBJECTIVE REFRACTION*

The different techniques of objective refraction are as follows:

- Retinoscopy
- Automated refractometry
- Keratometry.

Retinoscopy**

Retinoscopy is an objective method of finding the refractive error based on the principle of neutralization.

Principle

Retinoscopy is based on the principle that when light is reflected into eye, the direction in which light will travel in the pupillary area depends on the refractive status of the eye.

Types

1. Dry retinoscopy: Retinoscopy without the use of cycloplegic drugs is called dry retinoscopy.
2. Wet retinoscopy: Retinoscopy with the use of cycloplegic drugs is called wet retinoscopy.
3. Static retinoscopy: Retinoscopy done by relaxing the accommodation by cycloplegic

drugs or by asking the subject to fix at a distant target is called static retinoscopy.

4. Dynamic retinoscopy: Retinoscopy done by use of active accommodation by asking the subject to look at a near target.

Dry and static retinoscopy is done in elderly individuals, in whom the amplitude of accommodation is decreased. Wet and static retinoscopy is done in children and young adults in whom the accommodation is active. Dynamic retinoscopy is rarely done in clinical practice.

Mydriatics and Cycloplegic Agents in Retinoscopy

Cycloplegic drugs are used in retinoscopy in children and young adults in whom the accommodation is active. In children aged less than 7 years, atropine is used. In children between 7 and 12 years, homatropine is used and in children between the age group of 12 and 20 years, cyclopentolate is used. In the age group of 20–35 years with hypermetropia, homatropine or cyclopentolate is used.

In elderly individuals, only mydriatic drugs such as phenylephrine or tropicamide are used to enhance the visibility of pupillary reflex or to overcome the opacities of the media.

Procedure

Retinoscopy is done in a darkroom. The instruments required are retinoscope, trail set, trial frame and vision charts.

The examiner (ophthalmologist or optometrist) sits at a distance of 1 m from the subject/patient. Light is thrown into the subject's eye and the examiner observes the movement of red reflex in the pupillary area in both horizontal and vertical meridians by moving the retinoscope. The results are interpreted as:

1. Movement of red reflex with the movement of the retinoscope: Emmetropia, myopia of < 1 D, hypermetropia.
2. Movement of red reflex opposite to the movement of the retinoscope—myopia > 1 D.
3. No movement of red reflex: Myopia of 1 D.

The refractive error is estimated by neutralizing the movement of red reflex in both the vertical and horizontal meridian:

1. Red reflex, when moving opposite to the movement of the retinoscope is neutralized by concave lens (image moves with the movement in case of concave lens).
2. Red reflex, when moving with the movement of the retinoscope is neutralized by convex lens (image moves against the movement in case of convex lens).

In case of myopia or hypermetropia, the red reflex comes to neutralization in both the meridian by a single lens either concave or convex. In case of refractive errors associated with astigmatism, the neutralization of red reflex requires two different lenses of different refractive powers.

Postmydriatic test

When retinoscopy is done under mydriatics and cycloplegics, postmydriatic test (PMT) is done to check for the subjective acceptance of the objective refraction values, once the action of the mydriatic and cycloplegic drugs has completely disappeared. The PMT is done after 3 weeks in cases where atropine is used, after 3 days for homatropine, 1 day for cyclopentolate and after 4–6 hours where phenylephrine or tropicamide is used.

The refractive error is estimated by subtracting the deductions for the cycloplegic use and for the distance from the retinoscopy readings.

Deductions for mydriatics and cycloplegics: Atropine 1 D, homatropine 0.5 D, cyclopentolate 0.75 D, phenylephrine nil and tropicamide nil.

Deductions for distance: 1 for 1 m distance and 1.5 for 2/3 m.

The final values obtained after the deductions are checked for subjective acceptance before prescribing the glasses. Few examples are given below:

1. Calculate the refractive power in a patient with the retinoscopic readings of +2 in both the axes with retinoscopy done from 1 m distance using atropine as cycloplegic agent.

Ans: The refractive power is obtained by,

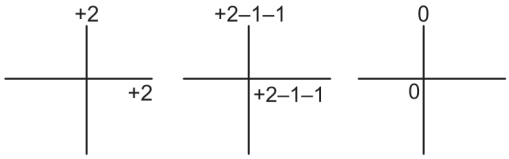
Refractive power = +2–1–1 = 0

where,

+2 : Retinoscopic reading

1 : Deduction for distance

1 : Deduction for cycloplegic



The refractive power correction required is 0 D, patient is emmetropic.

2. Calculate the refractive power in a patient with the retinoscopic readings of –2 in both the axes with retinoscopy done from 1 m distance using atropine as cycloplegic agent.

Ans: The refractive power is obtained by,

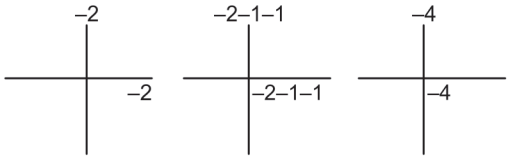
Refractive power = –2–1–1 = –4

where,

–2 : Retinoscopic reading

1 : Deduction for distance

1 : Deduction for cycloplegic



The refractive power correction required is –4 D, patient is myopic.

3. Calculate the refractive power in a patient with the retinoscopic readings of +3 in vertical axis and +4 in horizontal axis, both the axes with retinoscopy done from 1 m distance using atropine as cycloplegic agent.

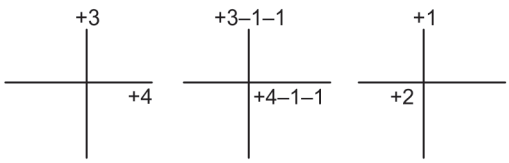
Ans: The refractive power is calculated in axis separately.

Refractive power in vertical axis

= +3–1–1 = +1

Refractive power in horizontal axis

= +4–1–1 = +2



The refractive power correction required is +1 D in vertical axis and +2 D in horizontal axis. The correction is given as a combination of spherical and cylindrical lens. +1 D sphere and +1 D cylindrical at 90°. Cylindrical lens is always given at 90° from the desired axis as cylindrical lens acts at 90° to its axis. In the example described here, +1 D more power is required in horizontal axis, hence it is given in vertical axis at 90°.

Retinoscope

Retinoscope is an instrument used to do retinoscopy. There are two types of retinoscopes:

1. Mirror retinoscope, which reflects light into the eye. Priestley-Smith retinoscope is an example for mirror retinoscope.
2. Self-illuminated retinoscope consisting of source of light in the instrument itself.

Automated Refractometry (Fig. 4.2.1)

Automated refractometry is done by computerized autorefractometer. It is the most popular method of objective refraction. It is used as an alternative to the retinoscopy as it is less time consuming and provides the refractive power readings rapidly.

Keratometer

Keratometer is an instrument, which measures the curvature of the cornea. It is used for measurement of corneal astigmatism.

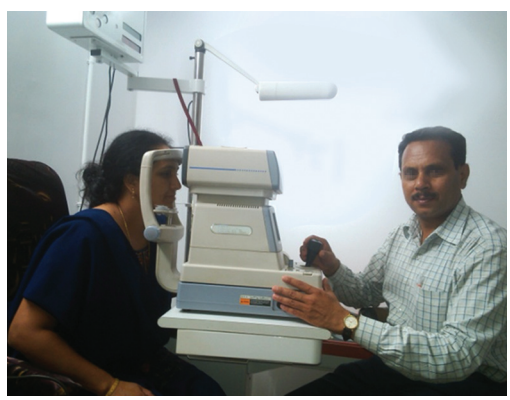


FIG. 4.2.1: Automated refractometry

TECHNIQUES OF SUBJECTIVE REFRACTION

Subjective refraction is done after objective refraction to find out the refractive power of the lenses to be prescribed depending on the subjective acceptance.

Subjective refraction is done in all patients, who can cooperate for subjective refraction by telling through which lenses they are subjectively better. Hence, subjective refraction cannot be done in children below the age of 1 year and mentally retarded patients. In them, the glasses are given based on the objective refraction findings.

Trial and Error Method

Trial and error method is the most common method of subjective refraction. In this method, each eye is tested separately after occluding the other eye by placing the weakest concave lens in case of myopia and strongest convex lens in case of hypermetropia. The power of the lens is increased or decreased depending on the subjective response from the patient. In case of cylindrical lenses, both power and axis are varied, and the best lens is chosen from the subjective response. The similar trial and error method is repeated in the other eye.

After subjective refraction, subjective verification of the refractive power is done. The spherical power is verified by duochrome test or FRIEND test. The cylindrical power is verified by Jacksons cross cylinder or astigmatic fan test.

Correction for near vision, if required is done and added to the distant correction. Finally, the refractive power is prescribed for correction of the refractive error either in the form of spectacles or contact lenses.

GIST BOX 4.2

- Refraction in eye is defined as a process by which the light rays are focused onto the light sensitive layer of the retina.
- Objective refraction is done without active participation of the patient. The various techniques of objective refraction are retinoscopy, automated refractometry and keratometry.
- Subjective refraction is done by participation of the subject or the patient. Trial and error method is the most common type of subjective refraction.

CHAPTER

4.3 Refractive Errors

Eye works as a convex lens focusing the rays of light, which enter the eye into a single point called focal point. The distance between the focal point to the center of the lens is called focal length. The ability of the eye to change its focal length depending on the distance of the object from the eye in order to focus the objects makes the eye a unique optical system. This ability of the eye to adjust or vary the refractive power is because of accommodation.

EMMETROPIA*



The word emmetropia is derived from Greek word emmetros means well-proportioned indicating that refractive power and axial length of the eye are in proportion, so that parallel rays of light coming from more than 6 m or infinity are focused on the retina with lens being in a relaxed state or without exerting accommodation.

Definition

Emmetropia is a state of normal refraction of the eye in which parallel rays of light coming from more than 6 m or infinity are focused on the retina with lens being in a relaxed state or without exerting accommodation (Fig. 4.3.1).

AMETROPIA*

Ametropia is a state of abnormal refraction of eye, in which parallel rays of light coming from more than 6 m or infinity are focused either in front or behind of retina with lens being in a relaxed state or without exerting accommodation.

Ametropia or refractive error affects millions of people in worldwide and it is the most common cause for which people visit ophthalmologist or eye clinic.

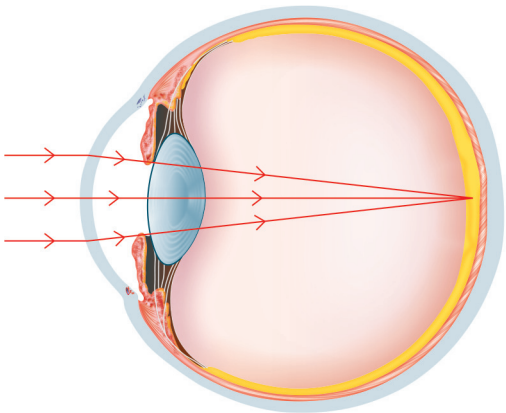


FIG. 4.3.1: Emmetropia

Ametropia includes:
- Myopia
- Hypermetropia
- Astigmatism.



At birth, the eyes show ametropia, with full-term babies showing hypermetropia. The hypermetropia is in the range from +2 to +3 diopters. The preterm babies show myopia. Emmetropia is achieved by 6–7 years of age.

The interesting fact is that the hypermetropia will come back as the age advances because of sclerosis of lens, thus making it in the normal course of hypermetropia at both extremes of ages.

MYOPIA***

Definition

Myopia is a type of anisometropia in which parallel rays of light coming from more than 6 m or infinity are focused in front of the retina with lens being in a relaxed state or without exerting accommodation (Fig. 4.3.2).

The word myopia is derived from Greek words 'myein' and 'ops', which means 'to shut or squeeze the eyes', because of the fact that myopic individuals see by squeezing the eyes, as this improves the vision because of pinhole effect.

Myopia is called nearsightedness or shortsightedness, as myopics will be able to see only near objects clearly and distant objects are blurred.

Myopia is the commonest type of refractive error with a prevalence of up to 80% in Asian countries and 20–30% in the Western countries. The etiopathogenesis and clinical features depend on the clinical type of myopia.

Optics of Myopia

Parallel rays of light coming from infinity are focused in front of the retina with accommodation at rest.

Optical treatment of myopia is by prescription of concave lens to diverge the rays and to make them fall on the retina.

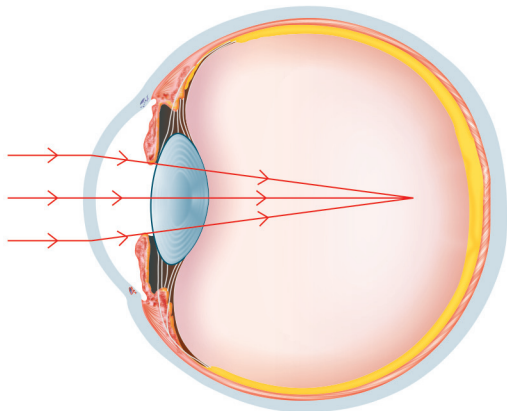


FIG. 4.3.2: Myopia

Divergent rays of light coming from near are focused on the retina without the effort of accommodation; hence, near vision is good. Since accommodation is not required for near vision in myopics, it may lead to convergence insufficiency.

Classification of Myopia



Depending on the amount of myopia, it is classified into:
- Low myopia: Myopia of less than –3.0 D
- Medium myopia: Myopia of –3.0 to –6.0 D.
- High myopia: Myopia of more than –6.0 D.

By convention, myopia of more than –6.0 D is called pathological myopia.

Clinically, myopia is classified into:
- Congenital myopia
- Simple myopia
- Pathological myopia
- Nocturnal myopia
- Pseudomyopia
- Induced myopia.

Congenital Myopia

Congenital myopia is a clinical type of myopia seen since birth. Myopia is seen more commonly in preterm babies. It can be unilateral or bilateral condition and may be associated with other

congenital anomalies such as megalocornea. The refractive error is up to –10 D. It presents similar to pathological myopia with enlarged or elongated eyeball at birth and all the fundus features except that progression is absent or rare. Unilateral cases of congenital myopia may lead to amblyopia.

Simple Myopia or Developmental Myopia

Simple myopia is the most common clinical variety of myopia seen in children and in adults.

Etiopathogenesis

Etiopathogenesis is because of physiological error in the growth of the eyeball caused by one of the mechanisms mentioned below:

- Increase in the axial length of the eyeball leading to axial myopia
- Increase in the curvature of the cornea and or lens leading to curvature myopia.



Normally, the axial length and power of the eyeball are inversely and proportionately related to each other.

An increase in the axial length without proportionate increase in the refractive power of the eye or increase in the refractive power of the eye without proportionate increase in the axial length of the eye causes simple myopia.

More close work, e.g. reading, watching television (TV) from near and excessive use of computers, in childhood has been implicated as a cause for myopia. The explanation put forth is excessive near work leading to near point stress affecting the extraocular and intrinsic muscles of the eye altering the shape of the eye causing myopia. However, this theory fails to explain the occurrence of myopia in illiterates.



Myopics have problem in seeing far objects, which make it uncomfortable for them to participate in outdoor games or activities; hence, myopics will involve more in reading, watching computer or TV. The advantage is myopic children sit in the front benches in school and has a look of being studious.

Clinical course

1. Simple myopia usually presents in children called childhood myopia, presenting at the age of 5–10 years. It usually progresses with increase in the refractive error progressing at the rate from –0.5 D to –1.0 D per year. The progression usually stops by teenage and the refractive error usually will not exceed –5.0 D.
2. Simple myopia can present in the adults in the age group of 20–40 years and late adult onset simple myopia presenting in the age group of more than 40 years. The adult onset and late adult onset simple myopia usually progresses at a slower rate and progression stop by fifth decade.

Symptoms

- Diminution of vision for distance of varying degrees depending on the amount of refractive error
- Asthenopic symptoms such as eye strain, headache seen in cases of mild refractive error.

Signs

Examination usually shows normal eye; large prominent eye is seen in cases associated with increased axial length of the eyeball. Retinoscopy shows myopic refraction and the refractive error usually will not exceed –6.0 D. Fundus examination shows normal retina; degenerative retinal changes commonly seen in pathological myopia are usually absent.

Diagnosis

Diagnosis is made by clinical features and by retinoscopy findings.

Treatment

1. Optical treatment of myopia: It is done by appropriate concave lenses to diverge the rays of light and to make them fall on the retina to form the image. Concave lenses can be prescribed in the form of spectacles and contact lenses (Fig. 4.3.3).
2. Surgical treatment of myopia: It is done by refractive surgeries. Laser-assisted in situ keratomileusis (LASIK), photorefractive keratectomy, phakic intraocular lens (IOL) implantation and radial keratotomy are the commonly performed refractive surgeries to correct myopia.

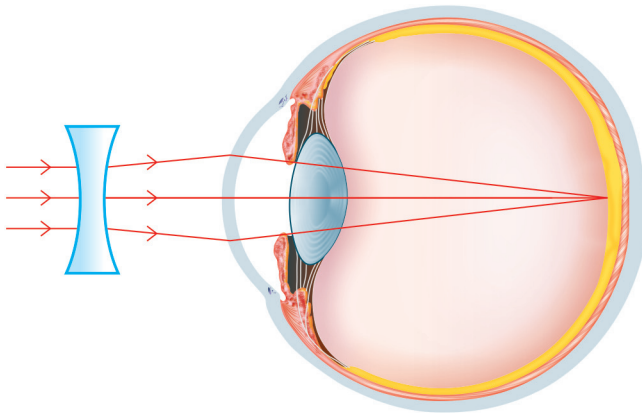


FIG. 4.3.3: Optical treatment of myopia by concave lens

Refractive surgeries for myopia are:*

- Radial keratotomy
- Photorefractive keratectomy
- LASIK
- Laser-assisted subepithelial keratectomy (LASEK)
- Epi-LASIK
- Customized LASIK
- IntraLase LASIK
- Phakic IOL
- Intrastromal corneal ring segments.

Pathological or Degenerative Myopia

Pathological myopia is a clinical type of myopia characterized by degenerative changes because of rapid increase in the axial length of the eyeball. Pathological myopia is usually more than –6.0 D with axial length of more than 25 mm.**

Etiopathogenesis

Etiopathogenesis is characterized by manifestation in early childhood by 5 years of age and increasing rapidly reaching –15 to –30 D by 25 years of age. Hereditary factors play an important role in the pathogenesis of the disease. The pathogenesis of development of pathological myopia is explained by following two theories:

1. Mechanical theory: This theory states that distension of sclera or weakening of sclera caused by prolonged elevated intraocular pressure, sustained accommodation and increased close work causes myopia by increasing the axial length.
2. Biological theory: This theory states that hereditary and growth factors play an important role in the development of myopia. Normally, two thirds of the growth in the length of the eyeball is achieved by 4 years of age; afterwards, it shows slow growth. If the growth of the eyeball continues rapidly, it leads to pathological myopia.

Pathological myopia is seen in association with systemic conditions such as Marfan's syndrome, Stickler's syndrome, Down syndrome, gyrate atrophy, albinism, etc.

Pathology

The pathological changes in pathological myopia are because of increased axial length of the eyeball as a result of hereditary and growth factors leading to degeneration of the choroid, retina and vitreous. The elongation of the eyeball is more pronounced in the posterior part of the eyeball predominantly involving the structures behind the lens.

The retina shows tessellated appearance because of atrophy of the retinal pigment epithelium and exposure of the underlying large choroidal vessels. The atrophy of the retinal pigment epithelium and choroid results in visibility of underlying white sclera visible around the optic disk called myopic crescent.

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