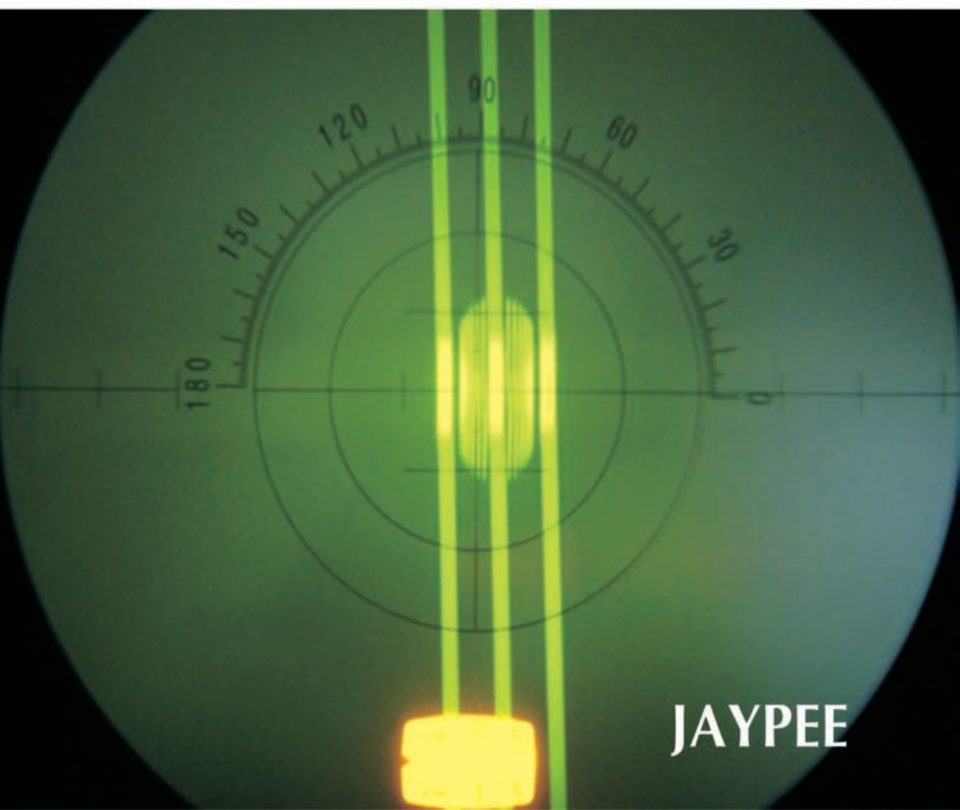
Textbook of Visual Science and Clinical Optometry

Bikas Bhattacharyya

Foreword
Debashish Bhattacharya



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Bikas Bhattacharyya MBBS (Honours), MS, DO
Consultant Eye and Laser Surgeon
Apollo Gleneagles Hospitals, Kolkata
Sambhu Nath Pandit Hospital, Kolkata
Wockhardt Medical Centre
Kolkata, West Bengal, India

Foreword
Debashish Bhattacharya

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USA Office
1745, Pheasant Run Drive, Maryland Heights (Missouri), MO 63043, USA,
Ph: 001-636-6279734 e-mail: jaypee@jaypeebrothers.com, anjulav@jaypeebrothers.com

Textbook of Visual Science and Clinical Optometry

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To
My parents Prativa Bhattacharya and
Late Biresh Chandra Bhattacharya
along with
My parents-in-law
Geeta Roychowdhury and
Late Satyabrata Roychowdhury

Foreword

Textbook of Visual Science and Clinical Optometry is a wonderful knowledge book for the ophthalmic practitioners, optometrists and students of ophthalmology.

This book explains the anatomy and physiology of the eye in a very well-formatted concise manner. It enlightens the optical defects and its correction in a most lucid and methodical way. In the glamour of ophthalmic innovations, the fundamental optics and refraction of the eye have become a forgotten territory.

I thank Dr Bikas Bhattacharyya for bringing out this book in such a "transparent and structured format". Bikas, 2 years junior to me in Medical Education in the same University, is always remembered for his unusual inclination to minute details and documentation. This book is reflection of his qualities.

I am sure we will learn a lot of skills from this book and use it for more efficient eye care. This will be the most fitting tribute to the hard work that he has put into writing this book.

Dr Debashish Bhattacharya
Chairman
Disha Eye Hospital and Research Centre (P) Ltd
Barrackpore, West Bengal, India

Preface

Textbook of Visual Science and Clinical Optometry is designed to cater to the needs of eye care team which includes ophthalmologists, ophthalmology residents, optometry students and ophthalmic technicians.

The book includes 18 chapters which are divided into 6 sections and each chapter is supplemented by numerous illustrations. Every attempt is made to make this book as clinically relevant as possible.

Section 1 to 3 deal with the normal human eye and its optical principle. Section 4 deals with the different types of refractive errors and its correction. Section 5 stresses on the various optical lenses, frames, measurements and contact lenses. Knowledge on these topics (Section 5) is usually not covered in books on ophthalmology. The last section is unique in a way as it covers three special chapters on ophthalmic instrumentation techniques, low visual aids and paediatric eye examination, which is invaluable to all those involved in eye care.

I hope that my humble efforts would prove successful in helping the beginners in ophthalmology. I have tried to make the topics as comprehensive and simplified as possible. However, certain inaccuracies may arise for which I apologise sincerely.

Any suggestions and comments on the book would be greatly appreciated.

Bikas Bhattacharyya
e-mail: drbhatta_bikas@yahoo.co.in

Acknowledgements

During my residency training and subsequent practising years, I felt the need of a comprehensive book covering all aspects of practical ophthalmic examinations and clinical optics.

I would like to thank M/s Appasamy Associates, Chennai, India for giving me the relevant photographs for publication.

I would also like to express my gratitude to Mr Sirajul Mullick, Department of Optometry Science (DOS) for the invaluable assistance he has extended to me during preparation of the chapters related to clinical optometry.

I would like to convey my gratitude to M/s Jaypee Brothers Medical Publishers (P) Ltd, New Delhi and all the technical staff.

I would also like to thank all my colleagues in different institutions for their continued encouragement.

Finally, I would like to thank my wife and children for their continued support and their patience for tolerating my preoccupation with the book.

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SECTION 1: ANATOMY

SECTION 2: PHYSIOLOGY AND NEUROLOGY OF VISION

SECTION 3: LIGHT AND OPTICAL PRINCIPLES

SECTION 4: REFRACTIVE ERRORS AND CORRECTION

Abbreviations

AC	Anterior chamber
AC/A	Accommodative convergence / Accommodation ratio
add	Addition for near vision
ARC	Abnormal retinal correspondence
ARMD	Age-related macular degeneration
BE	Both eyes
BIO	Binocular indirect ophthalmoscopy
BOZD	Back optic zone diameter
BOZR	Back optic zone radius
BRAO	Branch retinal artery occlusion
BRVO	Branch retinal vein occlusion
BVP	Back vertex power
CB	Ciliary body
cd	Candela
C/D	Cup disc ratio
CF	Counting fingers
CL	Contact lens
CLARE	Contact lens acute red eye
CME	Cystoid macular oedema
CNV	Choroidal neovascularisation
cpd	Cycle per degree
CRAO	Central retinal arterial occlusion
CRVO	Central retinal vein occlusion
CR-39	Columbia Resin 39
Ct	Carat
CVS	Computer vision syndrome
D	Diopter
DBL	Distance between lenses
DBR	Distance between rims
Dk	Oxygen permeability

Dk/t	Oxygen transmissibility
ECCE	Extracapsular cataract extraction
EOG	Electrooculogram
ERG	Electroretinogram
ERP	Early receptor potential
EUA	Examination under anaesthesia
EW	Extended wear contact lens
FAZ	Foveolar avascular zone
FM100	Farnsworth-Munsell 100 Hue test
ftcs	Footcandles
FVP	Front vertex power
GAG	Glycosaminoglycans
GPC	Giant papillary conjunctivitis
HEMA	Hydroxyethyl methacrylate
HM	Hand movements
ICCE	Intracapsular cataract extraction
IO	Inferior oblique
IOL	Intraocular lens
IOP	Intraocular pressure
IPD	Interpupillary distance
IR	Infrared, inferior rectus
J	Jaeger type notation
KCS	Keratoconjunctivitis sicca
KP	Keratic precipitates
LE	Left eye
LPS	Levator palpebrae superioris
LR	Lateral rectus
LVA	Low vision aid
M	Magnification
MAR	Minimum angle of resolution
MR	Medial rectus
N	N system of notation
n	Index of refraction
nm	Nanometer
OD	Oculus dexter, i.e. right eye
OKN	Optokinetic nystagmus
OS	Oculus sinister, i.e. left eye

OU	Oculus uterque, i.e., both eyes
PAL	Progressive addition lens
PAM	Potential acuity meter
PAS	Peripheral anterior synechiae
PD	Pupillary distance
PL	Perception of light
PMMA	Polymethyl methacrylate
POAG	Primary open-angle glaucoma
PVD	Posterior vitreous detachment
PXF	Pseudoexfoliation
RAPD	Relative afferent pupillary defect
RE	Right eye
RGP	Rigid gas permeable contact lens
RPE	Retinal pigment epithelium
SO	Superior oblique
SR	Superior rectus
TD	Total diameter
TM	Trabecular meshwork
UV	Ultraviolet
V	Abbé's number/constringence/V-value, vision
VA	Visual acuity
VEP	Visual evoked potential
VER	Visual evoked response
VKC	Vernal keratoconjunctivitis
α	Angle alpha
Δ	Prism diopter
κ	Angle kappa
λ	Angle lambda; wavelength
∞	Infinity

Section 1

Anatomy

CHAPTER 1

Anatomy of the Eyeball

INTRODUCTION

Eyeball is the peripheral organ of vision. Image of external world is reflected here and is transferred into visual impulses. It consists of segments of two spheres, where the smaller transparent one called cornea is placed in front of the other. Due to this anatomical shape anteroposterior diameter is more than vertical and horizontal diameter.

Eyeball consists of three coats or tunics (Fig. 1-1):

a. External fibrous—It is formed by transparent cornea in front, opaque sclera behind and their junction called limbus.
b. Intermediate vascular—It is formed by uveal tract consisting of iris, ciliary body and choroid.
c. Internal neural—It is formed by retina, which along with optic nerve is considered as the anterior prolongation of the brain.

CONTENTS

a. Aqueous humour
b. Crystalline lens held by zonule of Zinn
c. Vitreous humour.

DIMENSIONS (IN EMMETROPIC EYE)

Anteroposterior	—	24 mm
Horizontal	—	23.5 mm
Vertical	—	23 mm

Anteroposterior length of the eyeball at birth is 17.3 mm and it reaches adult size at 7-8 years.

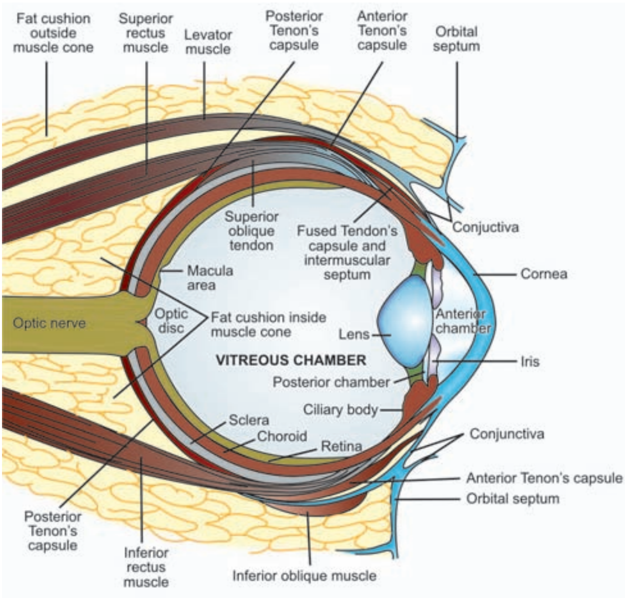


Fig. 1-1: Horizontal section of the eyeball

LOCATION

It is situated in the anterior part of the orbit, closer to the roof than the floor.

CHAMBERS

There are three chambers inside the eyeball:

a. Anterior chamber
b. Posterior chamber
c. Vitreous chamber.

Movements of the eyeball are governed by six extrinsic muscles.

CORNEA

- Cornea forms the transparent and anterior 1/6th of the external fibrous coat of the globe of the eyeball.
- It is just like glass cover of a watch which is set on the sclera.
- It is oval from front and circular from behind.
- It is the main refracting medium of the eye.

DIMENSIONS

Front/anterior	Horizontal diameter	— 12 mm
	Vertical diameter	— 11 mm
Back/posterior	Horizontal diameter	— 11.5 mm
	Vertical diameter	— 11.5 mm
Thickness	At the center	— 0.50 to 0.58 mm
	At the periphery	— 1 mm
Radius of curvature	Anterior surface	— 7.8 mm
	Posterior surface	— 6.5 to 7 mm
Refractive index	— 1.376	
Dioptric strength	— +42.5 Diopter	

At birth the size of the cornea is 80% of it's adult size and it reaches it's adult size at 3 years of age.

HISTOLOGY

Cornea consists of five layers (Fig. 1-2).

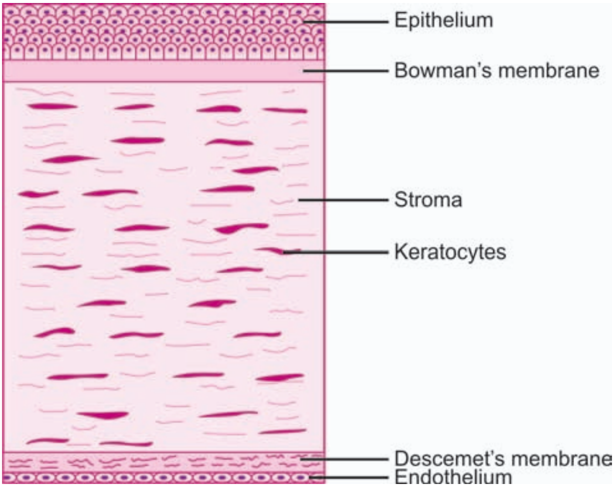


Fig. 1-2: Layers of the cornea

From the external surface the layers are as follows.

Stratified Squamous Epithelium

It is composed of 5–6 layers of nonkeratinised cells (Fig. 1-3), mounted on a basement membrane and continuous with the bulbar

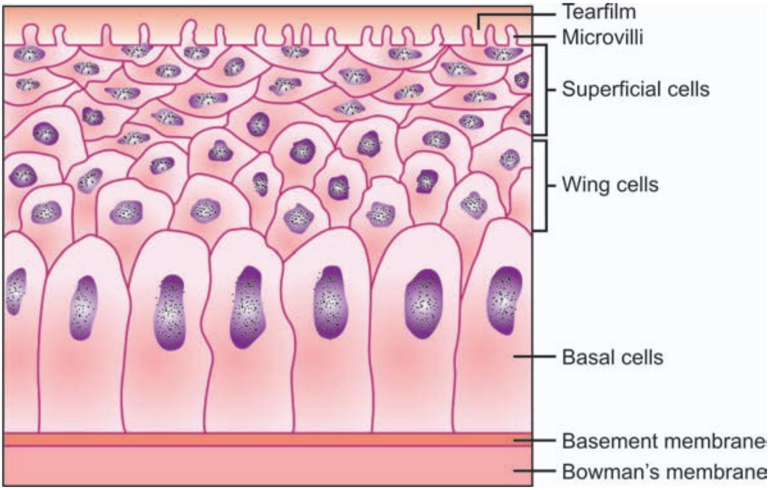


Fig. 1-3: Layers of the corneal epithelium

conjunctiva at the limbus. Life span of epithelial cells is roughly a week.

i. *Superficial cells (or Squamous cells):* It is 2–3 cell layered and the cells are polyhedral. Outer surfaces of these cells have projections called microvilli and microplicae. These projections extend into the mucin layer of precorneal tearfilm and help in retaining the tearfilm.

ii. *Wing cells (or Umbrella cells)*: It consists of also 2–3 layered polyhedral cells with their concave base fitting over the apex of the basal cells. These cells send wings or process between the basal cells.

iii. *Basal cells*: It is a single layer of columnar cells with flat bases and rounded apices (or head). These are germinal cells and show mitosis. New cells are gradually pushed superficially.

iv. *Basement membrane*: It is formed by secretions from the basal cells.

Despite lack of vascularity *corneal epithelium is capable of active regeneration* after injury or abrasion.

Bowman's Membrane

It is the modified condensed anterior layers of the corneal stroma. It is acellular and composed of randomly oriented fine collagen fibrils. Once damaged, the *Bowman's membrane cannot regenerate*. However, it exhibits strong resistance against infection and injury. It is well-demarcated from the corneal epithelium. So it is easy to strip the epithelium from the Bowman's membrane.

Stroma (Substantia propria)

It is the forward continuation of sclera. It accounts for 90% of corneal thickness. It consists of approximately 200 layers of parallel collagen fibrils, parallel to the surface of the cornea, surrounded by a ground substance of mucopolysaccharide. Two types of cells are found in the stroma.

i. *Keratocytes (or Corneal Corpuscles)*: They secrete collagen and the ground substance and lie within the collagen lamellae.
ii. *Wandering leucocytes*: They are derived from the limbal vessels.

Cornea is the most sensitive structure in the body due to presence of plenty nonmedullated nerve fibres in the stroma.

Descemet's Membrane

It is formed by secretion of corneal endothelium. Hence, it is a modified basement membrane of the endothelium. It is well-defined from the corneal stroma. It has wart-like elevations at the periphery termed as Hassall-Henle bodies. It terminates peripherally at the Schwalbe's line. It is strong and *capable of regeneration* after injury.

Endothelium

It is the deepest layer of cornea consisting of a mosaic of single layer of hexagonal cells, bound together and continuous with the endothelium of the anterior surface of the iris. Endothelial cells are responsible for maintaining relative dehydration (deturgence) of corneal stroma and transparency. Endothelial cells of the cornea can be seen by specular reflection with the slit-lamp biomicroscope. Once damaged, the *endothelial cells do not regenerate*. At birth the endothelial cell count is 4500 cells/mm^2. In the first year of life 25% reduction in cell count occurs. Thereafter, a progressive reduction in endothelial cell count occurs with increasing age. Average endothelial cell count in adult is 2800 cells/mm^2. Great variation in size of the endothelial cells is termed polymegathism. It is often observed after ocular disease, trauma and prolonged contact lens wear.

BLOOD SUPPLY

The cornea is avascular. However, small plexuses from the anterior ciliary vessels penetrate the periphery of the cornea for roughly 1 mm and are actually within the subconjunctival tissue which overlaps the corneal periphery.

NERVE SUPPLY

It is supplied by anterior and posterior ciliary nerves, branches of the ophthalmic division of the trigeminal (Vth cranial) nerve. They form a pericorneal plexus and enter the cornea via the limbus, as 60 – 80 myelinated trunks. They shed their myelin sheaths after reaching few mm inside the cornea and divide into two groups. The superficial group forms plexuses under the Bowman's membrane and the epithelium. The deeper group forms plexuses within the peripheral area of the stroma. *The Descemet's membrane, endothelium and the central part of the stroma are devoid of any nerves.*

SCLERA

- Sclera forms the tough, white, opaque posterior 5/6th of the external fibrous coat of the eyeball.
- Sclera is thickest posteriorly (1 mm) and thinnest just behind the insertion of the extraocular muscles (0.3 mm). The thickness around the limbus is 0.6 mm.
- Scleral spur is a concentric band of sclera, triangular in section, lying posterior to the Schlemm's canal and trabecular meshwork (TM).
- Sclera is pierced by 3 sets of apertures:
    a. Posteriorly around the optic nerve through which pass the long and short posterior ciliary vessels and nerves.
    b. In the middle, vortex veins (four in number) exit 4 mm behind the equator of the globe.

c. Anteriorly pierced by anterior ciliary vessels and perivascular lymphatics.

- Sclera has three layers from outside inward:
  a. Episclera
  b. Sclera proper
  c. Lamina fusca (or suprachoroid).

FUNCTION OF THE SCLERA

It protects the eyeball by rendering mechanical strength and support.

BLOOD SUPPLY

It is relatively avascular. However, a rich vascular plexus is formed by episcleral and choroidal vessels, anterior to the insertion of the rectus muscles of the eye. The congestion of these vessels is the basis of the clinical sign "ciliary congestion".

NERVE SUPPLY

It is richly supplied by short ciliary nerves posteriorly and long ciliary nerves anteriorly.

LIMBUS

- It is the transitional area between the cornea on one side and sclera along with conjunctiva on the other.
- Dimensions – Width Superiorly – 2 mm
  Inferiorly – 1.8 mm
  Nasally and Temporally – 1.4 mm
  Thickness – 0.7 mm
- Knowledge of surgical anatomy of the limbus (Fig. 1-4) is essential due to the fact that virtually all surgery for glaucoma is performed at the limbus since it contains trabecular meshwork (TM) internally.
- Midlimbal line is useful landmark because it overlies Schwalbe's line. It represents the junction between the bluish zone and the white sclera.

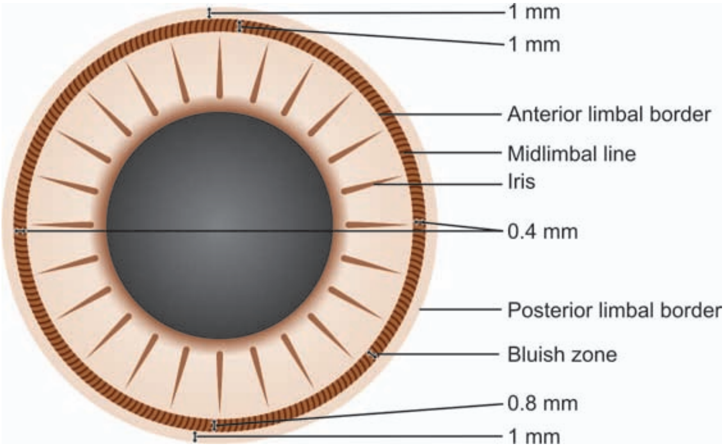


Fig. 1-4: Surgical anatomy of the limbus, dimensions and landmarks

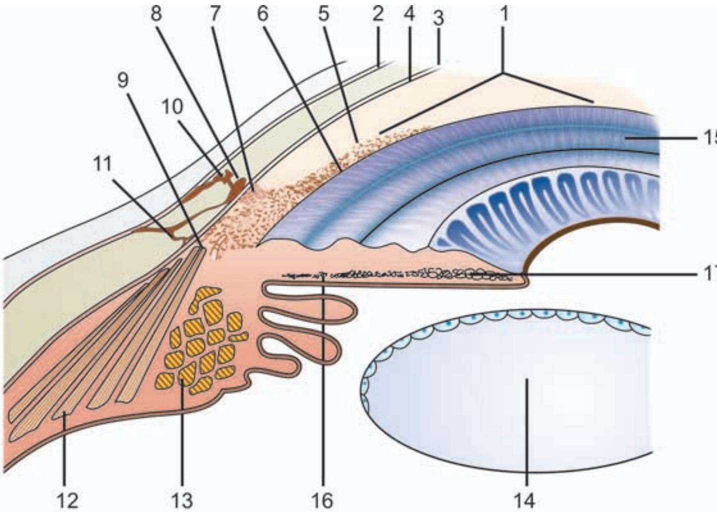
ANTERIOR CHAMBER

- It is a space filled with aqueous humour.
- It is bounded in front by the cornea and behind by the iris and pupil, i.e. part of the anterior surface of the lens. It is bounded laterally by the angle of the anterior chamber which is bounded by cornea and sclera anteriorly and root of the iris, the anterior part of the ciliary body and the scleral spur posteriorly (Fig. 1-5).
- Volume of anterior chamber — 0.25 cc
- Depth of the anterior chamber — 2.5 mm

The filtration structures present at the angle of the anterior chamber consists of (Fig. 1-5) from inside outwards the following:

TRABECULAR MESHWORK (TM)

It is triangular in shape with the apex arising from the termination of the Descemet's membrane (Schwalbe's line) and adjacent corneal stromal fibres. The base of the trabecular meshwork (TM) merges into the ciliary body and root of the iris. Trabecular meshwork is composed of circumferentially disposed flattened bands. Each of the bands have multiple perforations. The openings become progressively smaller as Schlemm's canal is approached. So,



1 = Anterior chamber, 2 = Bowman's membrane, 3 = Descemet's membrane, 4 = Endothelium, 5 = Schwalbe's line, 6 = Trabecular meshwork, 7 = Spaces of fontana, 8 = Canal of Schlemm, 9 = Scleral spur, 10 = Episcleral venous plexus, 11 = Intrascleral venous plexus, 12 = Circular ciliary muscle, 13 = Meridional ciliary muscle, 14 = Lens, 15 = Iris, 16 = Dilator pupillae and 17 = Sphincter pupillae

Fig. 1-5: Structures of the angle of the anterior chamber and the anterior chamber

through these openings tortuous canals (spaces of Fontana) exist between the anterior chamber and the Schlemm's canal.

JUXTACANALICULAR TISSUE

It lies between the deeper part of the trabecular meshwork and the Schlemm's canal.

SCHLEMM'S CANAL

It is a circular venous sinus and plays significant role in the drainage of the aqueous humour. It is lined by a continuous layer of endothelial cells joined by junctions which are not truly tight. Only 1% of aqueous drains through these tight junctions. Villi from the cytoplasm of the endothelial cells projects into both juxtacanalicular tissue and the Schlemm's canal. Macropinocytic vesicles and micropinocytic vesicles presents in the cytoplasm act as the major outflow pathway.

COLLECTOR CHANNELS

Twenty-five to thirty-five collector channels drain aqueous from the outer wall of the Schlemm's canal to the anterior ciliary veins via the intrascleral and episcleral plexuses. Aqueous vein also drains aqueous directly into the anterior ciliary veins.

POSTERIOR CHAMBER

- It is also a space filled with aqueous humour
- Aqueous humour is secreted here by the ciliary processes
- Volume of posterior chamber — 0.06 cc.
- It is bounded in front by the posterior surface of the iris and anterior surface of the lens and zonules of Zinn from behind. It is bounded laterally by the ciliary processes of the ciliary body.

UVEAL TRACT

This is the intermediate vascular coat of the eyeball consisting of the three following parts; Iris, Ciliary Body and Choroid.

IRIS

It is the most anterior part lying in front of the crystalline lens and behind the cornea. It is circular in shape with a central opening called pupil (like a diaphragm of a camera). It is peripherally attached to the middle the anterior surface of the ciliary body. Anterior surface of the iris is divided by a ridge called collarette (thickest part) into smaller pupillary zone and larger ciliary zone (Fig. 1-6). The collarette is formed by roughly circular series of ridges and minor arterial circle of iris. Major arterial circle which supplies blood to the iris is located in the ciliary body adjacent to the root of the iris (Fig. 1-7). The peculiarity of the iris vessels is that, they usually do not bleed when the iris is cut. This is due to the fact that they are enclosed by thick collagen bundles.

Histology

It consist of 4 layers:

a. *Anterior endothelium*—It is continuous with the corneal endothelium. Iris crypts of Fuchs are pit-like depressions (Fig. 1-6)

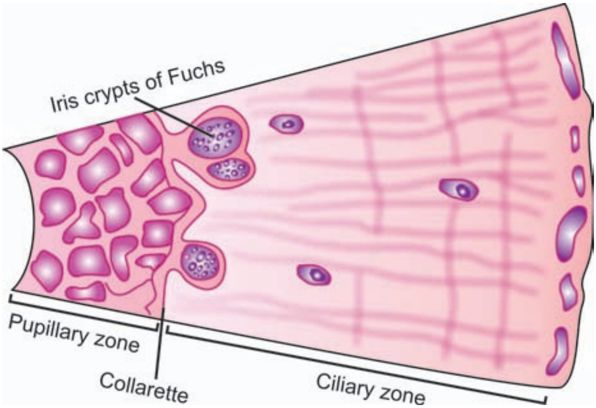


Fig. 1-6: Anterior surface of the iris

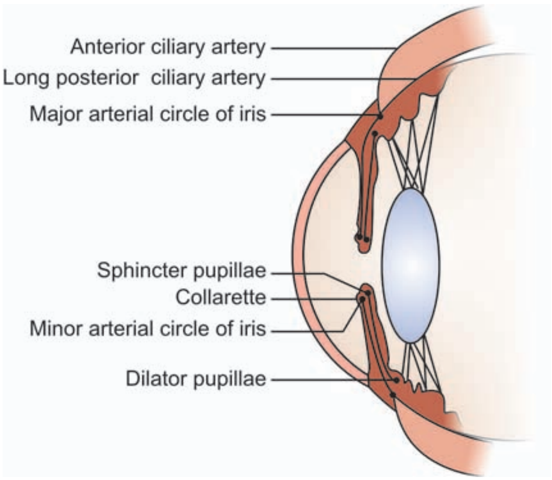


Fig. 1-7: Location of arterial circles and unstriated muscles of the iris

caused by the focal absence of anterior endothelium. These crypts are present near collarette and the root of the iris. Iris crypts located peripherally are difficult to visualise without gonioscopy.

b. *Stroma*— The sphincter pupillae muscle, vessels and nerves of the iris and pigment cells are embedded in the connective tissue of the stroma. Sphincter pupillae muscle is, unstriated and involuntary, 1 mm wide, present near the posterior surface in a circular fashion (Figs 1-5 and 1-7).

c. *Posterior membrane*—It consists of a thin layer of unstriated and involuntary muscle fibres, called dilator pupillae. Dilator pupillae is arranged radially near the root of the iris (Fig. 1-7). Dilator pupillae fibres originate from the ciliary body and fuse with the sphincter pupillae muscle (Fig. 1-5). Contraction of the dilator pupillae draws the pupillary margin towards the ciliary body to cause dilation of the pupil.
d. *Posterior epithelium*—It consists of two layers of pigmented epithelium, both of which have originated developmentally from the retina. They are continuous with each other at the pupillary margin. Anterior layer of epithelium contains flat spindle cells whereas, the posterior layer contains large cubical cells.

Function of the Iris

The central opening of the iris, i.e. pupil regulates the entry of light into the eye through the actions of the dilator pupillae and the sphincter pupillae muscles.

Blood Supply

It is from the minor and major arterial circle of the iris.

Nerves Supply

a. Sphincter pupillae—Oculomotor (IIIrd cranial) nerve
b. Dilator pupillae—Nerves from the cervical sympathetic
c. Sensory—Nasociliary nerve [a branch of 1st division of the trigeminal (Vth cranial) nerve].

CILIARY BODY

It is the intermediate part of the uveal tract. It extends from ora serrata to the root of the iris, where it is attached to the scleral spur. It is a circular band width of which is 5.9 mm nasally and 6.7 mm temporarily. It is divided into two anatomical parts:

a. *Pars plicata*: Anteriorly about 70 ridges (ciliary processes) are arranged in a radiating manner. The region of the ciliary processes is the most vascular area of the eye. The ciliary processes are actively involved in the secretion of the aqueous humour. Width of the pars plicata is 2 mm.

b. *Pars plana*: This part is smooth and extends upto ora serrata. During the operations of vitrectomy and lensectomy, ports are made in this area due to relative avascularity and it's location away from the crystalline lens.

It is roughly triangular in sagittal section with the base facing anteriorly. The external side of the triangle is against the sclera and here lies ciliary muscle which is unstriated and involuntary. Ciliary muscles form the chief mass of the ciliary body. It has three parts and a common ring shaped origin mostly from the scleral spur and partly from the trabecular meshwork (TM). The parts of the ciliary muscle are as follows:

a. *Meridional (or Brucke's muscle):* It runs anteroposteriorly to be inserted into the suprachoroid and forms the main mass of the ciliary body (Fig. 1-5).
b. *Radial*: They are embedded in the meridional fibres and inserted into the root of the iris close to the dilator pupillae muscle.
c. *Circular (or Müller's muscle):* They remain in the anterior and inner portion of the ciliary body and run parallel to the limbus to form a concentric ring (Fig. 1-5).

Ciliary muscle is innervated by the parasympathetic fibres derived from the oculomotor (IIIrd cranial) nerve and sympathetic fibres through the short ciliary nerves. Stimulation of the parasympathetic nerve causes contraction of the ciliary muscle resulting in shortening of it's length. Thus, the whole muscle moves forward and inward. Consequently the zonule of Zinn (or suspensory ligament of lens), which suspends the lens, relaxes. This results in release of tension on the capsule of the lens, allowing it to become more convex. This is the basis of accommodation. Contraction of this muscle also opens up trabecular meshwork openings and facilitate aqueous humour outflow.

Inner surface of the ciliary body is covered by layers of epithelium, and are continuous with the similar layers of the iris. The outer layer consisting of flattened cells is continuous with the anterior pigment epithelium of iris and is also pigmented. The inner layer which consists of cubical cells, is continuous with the posterior pigment epithelium of iris. However, this layer is non-pigmented.

Functions of the Ciliary Body

a. Production of aqueous humour
b. It is involved in accommodation:

Contraction of the ciliary muscle
↓
Relaxation of zonule of Zinn
↓
Relaxation of tension on the lens capsule
↓
Increased curvature of the anterior lens surface
↓
Crystalline lens becomes more convex
↓
Near objects are focused on the retina

c. Increase outflow of aqueous through the trabecular meshwork:

Contraction of the meridional fibres of the ciliary muscle
↓
Increased traction on the scleral spur and trabecular meshwork attachment
↓
Opening of sinuous channels in the trabecular meshwork (spaces of Fontana)

d. Inner nonpigmented layer of the epithelium secretes hyaluronic acid, the essential component of the vitreous humour.

Blood Supply

It is supplied by two long posterior ciliary arteries and seven anterior ciliary arteries via major arterial circle of iris.

Nerve Supply

i. Ciliary muscle—It is supplied by the oculomotor (IIIrd cranial) nerve and the sympathetic nerve.
ii. Sensory— Nasociliary branch of the trigeminal (Vth cranial) nerve.

CHOROID

It is a highly vascular thin tunic located between the sclera and the retina and extends from ora serrata to optic nerve. It consists of four layers from outside inwards (Fig. 1-8):

a. Suprachoroid (Lamina fusca)
b. Layer of blood vessels
   i. Outer larger vessel layer (Haller's layer)
   ii. Inner smaller vessel layer (Sattler's layer).
c. Choriocapillaries—It is a layer of capillary plexus of fenestrated vessels and it nourishes outer half of the retina.
d. Membrane of Bruch—It is avascular, separating choriocapillaries from the pigment epithelium of the retina. It consists of outer lamina elastica and inner lamina vitrea, i.e. basement membrane of the pigment epithelium of the retina. It is an important constituent of the blood retinal barrier.

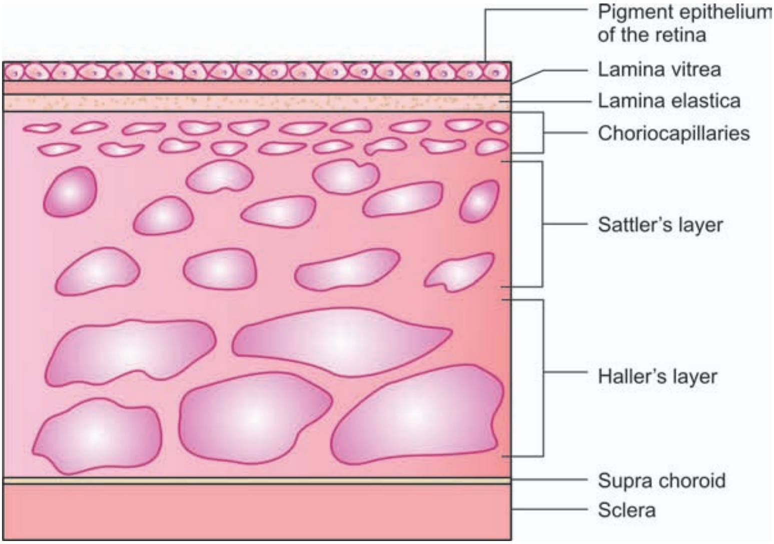


Fig. 1-8: Layers of choroid

Functions of the Choroid

a. It provides blood supply and nutrition to the retinal pigment epithelium (RPE) and outer half of the sensory retina.
b. It regulates ocular temperature.

Arterial Supply

it is supplied by the following group of arteries:

i. Short posterior ciliary arteries (20 in number)
ii. Long posterior ciliary arteries (2 in number)
iii. Anterior ciliary arteries (7 in number).

Venous Drainage

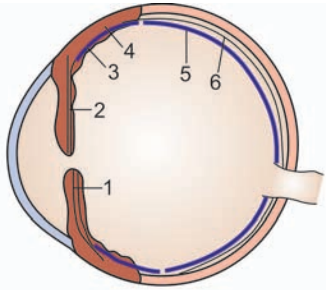
Venous blood from the iris, ciliary body and choroids is collected by a series of intermediate small veins, which drain into vortex veins (usually 4 in number). The vortex veins are located behind the equator of the eyeball. The vortex veins drain into cavernous sinus through superior and inferior ophthalmic veins.

The walls of the choriocapillaries are fenestrated which allow relatively free movement of fluids and solids between the choroids and the adjacent retinal pigment epithelium (RPE) via the Bruch's membrane. The Bruch's membrane offers no resistance to the fluid traffic.

RETINA

- It is the light receptive inner neural coat of the eyeball consisting of outer retinal pigment epithelium (RPE) and inner sensory retina with a potential space called subretinal space between them.
- It lies between the choroid and the vitreous.
- It extends from the optic disc to the ora serrata.
- Point of importance must be noted that the two pigment epithelium layers of the iris may be traced back upto retina. The anterior pigment epithelium of the iris continues as the outer pigment epithelium of the ciliary body and later forms the retinal pigment epithelium (RPE). The posterior pigment epithelium layer of the iris similarly continues to become the inner nonpigmented epithelium of the ciliary body. This again continues to form the inner nonpigmented sensory layer of the retina (Fig. 1-9).
- Surface area of the retina— 266 mm^2

- Thickness at the ora serrata – 125 μ
  Thickest at the macula – 350 μ
  Thinnest at the centre of the fovea – 90 μ



1 = Anterior pigment epithelium of the iris, 2 = Posterior pigment epithelium layer of the iris, 3 = Inner nonpigmented epithelium of the ciliary body, 4 = Outer pigment epithelium of the ciliary body, 5 = Inner nonpigmented sensory layer of the retina and 6 = Retinal pigment epithelium

Fig. 1-9: Continuation of the retina to epithelial layers of the ciliary body and iris

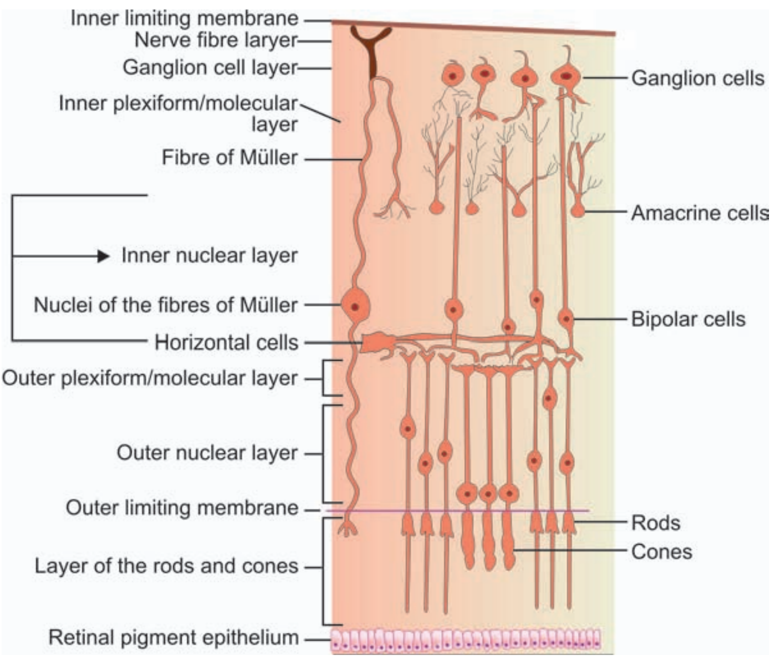


Fig. 1-10: Layers of the retina

LAYERS OF RETINA

Retina consists of 10 distinct layers (Fig. 1-10) from outside inwards of the following layers:

a. *Retinal pigment epithelium (RPE):* It is a single layer of flattened, mostly hexagonal cells which is firmly adherent to lamina vitrea of the choroid. On direct ophthalmoscopy the retina exhibits fine mottled appearance due to the following facts:
   i. The RPE cells are not equally pigmented.
   ii. Pigments in each RPE cells are distributed at the periphery of the cells and the central nuclear area remains relatively pigment free.

   The taller and narrower pigment cells at the macula confer darker colour to this region. RPE cells transport substances to the photoreceptor cells which are needed for metabolism. Free exchange of products of metabolism occur between the RPE cells and the photoreceptor cells.

b. *Layer of the rods and cones:* Rods and cones with their nucleus and processes form the sensory receptor. They are arranged on the external limiting membrane like a palisade. The rods contain visual purple called rhodopsin which combines vitamin A with protein. Rhodopsin is responsible for vision in dim light (scotopic vision) and peripheral vision. The cones are responsible for acuity of vision, vision in strong light (photopic vision) and colour vision.

   No. of rods— 125 million   No. of cones— 7 million

   Each photoreceptor, i.e. rod and cone consist of 3 parts;
   i. Outer and inner segment connected by a tubular connection called cilium in the layer of the rods and cones.
   ii. Cell body and nucleus in the outer nuclear layer.
   iii. Cell processes, i.e. axons that extend into the outer plexiform layer.

   Rod outer segment, cylindrical in shape, contains dense vertical stack of numerous lamellar discs. The inner segment of the photoreceptors consist of outer ellipsoid (containing large number of mitochondrias) and an inner myoid portion (containing endoplasmic reticulum). The cone outer segment is conical in shape. New rod discs are produced in the inner segments and are progressively displaced towards the pigment epithelium via the outer segment. Discarded rod discs are phagocytosed by the RPE cells.

c. *Outer limiting membrane:* It is a fenestrated membrane formed by fibres of Müller and pierced by the processes of the rods and cones.
d. *Outer nuclear layer:* This layer contains nuclei of the rods and cones.
e. *Outer plexiform/molecular layer:* It consists of;
   i. Arborisation of the axons of the rod and cone nuclei with the dendrites of the bipolar cells
   ii. Processes of the horizontal cells
   iii. The fibres of Müller.
f. *Inner nuclear layer:* This layer consists of;
   i. Bipolar cells
   ii. Horizontal cells
   iii. Amacrine cells
   iv. Nuclei of the fibres of Müller
   v. Capillaries of the central retinal artery and vein.

   Bipolar cells form the first order of neurons. Their nuclei are located in the inner nuclear layer and the dendrites arborise with the axons of the rods and cones in the outer plexiform layer. The axons of the bipolar cells synapses with the dendrites of the ganglion cells in the inner plexiform layer. The "midget" bipolar cells synapse with the individual cone feet plates while the rest of the bipolar cells synapse with both the rod spherules and cone feet.

   Horizontal cells are flat cells situated near the outer plexiform layer and send processes horizontally.

   Amacrine cells are pear shaped and send single process inwards to terminate in the inner plexiform layer. They are located near the inner plexiform layer. Both horizontal cells and amacrine cells form horizontal connections between adjacent rods and cones.
g. *Inner plexiform/molecular layer:* This layer contains;
   i. Mainly arborisation of the axons of the bipolar cells with the dendrites of the ganglion cells.

ii. Processes of the amacrine cells
iii. Fibres of Müller
iv. Branches of the retinal arteries and veins.

h. *Ganglion cell layer:* Ganglion cells are multipolar nerve cells with clear oval nucleus and well-developed Nissl granules. Ganglion cells form the second order of neurons. Their axons pass into the nerve fibre layer and arborize on cells in the lateral geniculate body and superior colliculus (central nervous system).

i. *Nerve fibre layer:* It consists of;
   i. Axons of the ganglion cells which pass through lamina cribrosa and form the optic nerve.
   ii. Fibres of Müller
   iii. Retinal vessels.

   The bundles of axons of ganglion cells run parallel to the surface of the retina and converge towards the optic disc. They are nonmyelinated. Nasal fibres reach optic disc directly. The temporal fibres pass above and below the macula to reach the optic disc (Fig. 1-11). The macular fibres directly reach the temporal side of the optic disc and form the papillomacular bundle (Fig. 1-11).

j. *Inner limiting membrane:* It is a thin hyaloid membrane separating the retina from the vitreous. The feet of the fibres of Müller are attached to it.

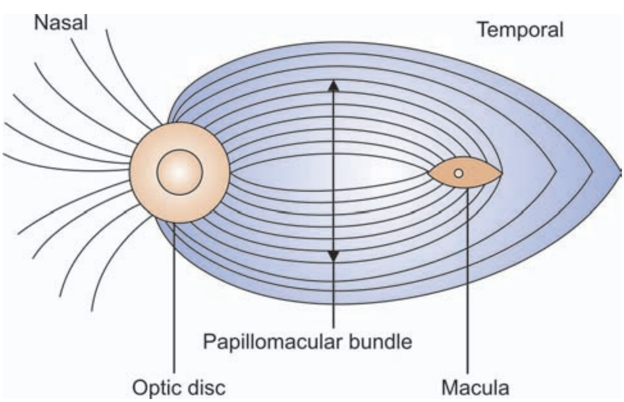


Fig. 1-11: Direction of nerve fibres reaching optic disc

LANDMARKS ON THE RETINA

a. *Ora serrata:* It is the extreme anterior end of the retina. It is located 8 mm from the limbus and 6 mm from the equator of the eyeball. Here the retina is firmly attached to the choroid. Also the vitreous is firmly attached to ora serrata. All the retinal elements tend to cease just posterior to ora serrata.

b. *Optic disc:* It is a vertically oval structure and it is called blind spot due to it's failure to evoke visual sensation. Only the nerve fibre layer is present here. It is pink coloured due to the presence of capillaries. There is a funnel shaped depression/excavation at the center and slightly to the temporal side. It is called physiological cup and is lighter in colour.

c. *Macula lutea:* It is an oval area situated temporal to the optic disc. It's centre lies 3.5 mm lateral to the optic disc. It is of the same size as the optic disc. At the macula, the ganglion cells are arranged in several layers and the outer plexiform layer is thickest. Rods progressively decrease in number towards the centre. The cones progressively increase towards the centre. It is nourished by the choriocapillaries.

d. *Fovea centralis:* It is the central depression of the macula lutea. Only cones are present in the fovea. It is the thinnest area of the retina and characterised by:

   i. Absence of rods, fibres of Müller, ganglion cells and nerve fibre layer.
   ii. Extreme thinness of inner plexiform layer, outer plexiform layer and inner nuclear layer.
   iii. Tall and slender cones.

Here the layers of the retina are spread aside to allow the light to fall straight on the cone to evoke maximum visual acuity. It is located 2 disc diameter, i.e. 3 mm temporal to the optic disc and just below the horizontal meridian. Here each cone is connected to only one ganglion cell through "midget" bipolar cells and synaptic connections. The above fact also makes fovea centralis responsible for maximum visual acuity. The centre of the fovea is called foveola (500 μm). The foveola doesn't contain any blood vessels and is called foveolar avascular zone (FAZ).

Retina is topographically divided into central 4.5 mm diameter zone (fovea centralis being the centre) called posterior pole, peripheral retina and intermediate equatorial retina.

BLOOD SUPPLY OF RETINA

a. Retinal pigment epithelium, layers of the rods and cones, outer limiting membrane and outer nuclear layer are avascular layer and are nourished by the choriocapillaries.
b. Outer plexiform layer is supplied by both the choriocapillaries and the retinal vessels.
c. Rest of the retinal layers are supplied by the retinal vessels.
d. Macula lutea and fovea is exclusively nourished by the choriocapillaries. Macula is occasionally supplied by a cilioretinal artery which emerges from the temporal margin of the optic disc. Cilioretinal vein is extremely rare.

The endothelial cells present in the capillaries of the retina are closely adherent to each other by tight junctions and prevent free flow of fluids and other solutes between the capillaries and the retinal tissue and form the blood-retinal barrier.

OPTIC NERVE

- Optic nerve consists of approximately 1 million axons of the ganglion cells of retina, glial cells and the meningeal sheaths.
- It extends from the optic disc to the optic chiasma.
- It can be divided into 4 portions depending on it's location;
  i. Intraocular— It extends from the optic disc to just posterior to the lamina cribrosa
  ii. Orbital
  iii. Intracanalicular— The portion within the optic foramen
  iv. Intracranial.

The optic disc is vertically oval, 1.5 mm in diameter. It is strikingly paler in colour than the surrounding retina. It is located 3 mm nasally and slightly at a upper level than the fovea. Physiological cup, the funnel shaped depression within the optic disc is lighter in colour than the peripheral neuroretinal rim. The nerve fibres are transparent within the retina and at the optic disc since, they are nonmyelinated. Just behind the lamina cribrosa they become opaque due to addition of myelination. The central retinal artery lies nasal to the central retinal vein at the optic disc.

The nerve fibres, i.e. axons of the ganglion cells pass through a sieve like structure in the sclera called lamina cribrosa and receive myelination resulting in increased diameter of 3.6 mm of the optic nerve.

BLOOD SUPPLY

The optic nerve is supplied from following sources;

- Arterial circle of Zinn
- Choroidal vessels
- Branches of retinal arterioles
- Intraneural branches of central retinal artery
- Pial branches of choroidal arteries
- Ophthalmic artery.

LENS

- It is a transparent biconvex crystalline structure situated between the iris and the vitreous humour.
- The older cells are concentrated towards the centre, whereas the younger cells remain at the periphery of the lens.
- It is attached to the ciliary body by the zonules of Zinn (or suspensory ligament). Zonuler fibres form 3 groups;
  - i. Arising from the pars plana and insert into the lens capsule anterior to the equator.
  - ii. Arising from the summits and valleys of the ciliary processes and pass backward to be inserted into the lens capsule posterior to the equator.
  - iii. Arising from the summits of the ciliary processes and insert directly at the equator.
- It is devoid of any nerve, vessel and connective tissue.
- Dimensions

  Diameter – 9 mm

  Thickness – 4 mm

  Radius of curvature of anterior surface – 10 mm

  Radius of curvature of posterior surface – 6 mm

STRUCTURE

Lens consist of (Fig. 1-12) the following:

Lens Capsule

It is acellular and envelops the lens completely. It is a basement membrane of the lens epithelium. It is thinnest at the posterior pole. Only the anterior capsule is lined by the single layer of epithelium.

Lens Epithelium

It consists of a single layer of cuboidal cells present in the anterior lens capsule (A – cells) and in the equatorial bow region (E – cells). The A – cells (LEC) present in the anterior capsule are not directly involved in the formation of new lens fibres. The equatorial bow/ E – cells show mitotic activity to form new lens fibres. As new cells are formed, these lens fibres elongate and lose their nuclei. Older fibres are continuously pushed centrally.

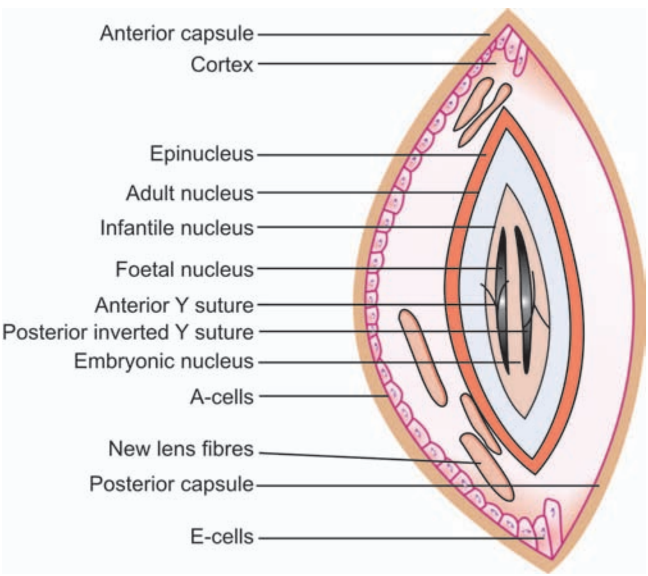


Fig. 1-12: Structure of the crystaline lens

Lens Substance/Material

It consists of the cortex, epinucleus, nucleus and sutures. The most externally located lens fibres which lie beneath the lens capsule form the cortex.

The fibres of central embryonic nucleus meet at the sutures shaped Y. The anterior Y suture is erect, whereas the posterior suture is inverted Y. As development proceeds successive layers of nucleus are formed externally and added to the central embryonic nucleus, viz. foetal, infantile and adult nucleus.

VITREOUS HUMOUR

It is a clear, transparent, colourless jelly that fills the posterior 4/5th of the eye, i.e. the space behind the lens and the zonule of Zinn. Volume of vitreous is 4.5 ml (approx.). Anteriorly vitreous has a saucer like depression called *fossa patellaris* to lodge the lens. Through it's centre runs hyaloid canal, which is remnant of the hyaloid artery. Vitreous humour is loosely adherent to the retina. However, it is firmly attached to the;

i. Margin of the optic disc (*Area Martegiani*)
ii. Pars plana of the ciliary body near ora serrata. 1.5 mm broad zone of the ciliary epithelium next to ora serrata (termed *vitreous base*).
iii. Macula
iv. Central 9 mm diameter zone of the posterior capsule of the lens (*ligamentum hyaloideo-capsulare of Weiger*, (Fig. 1-13)).

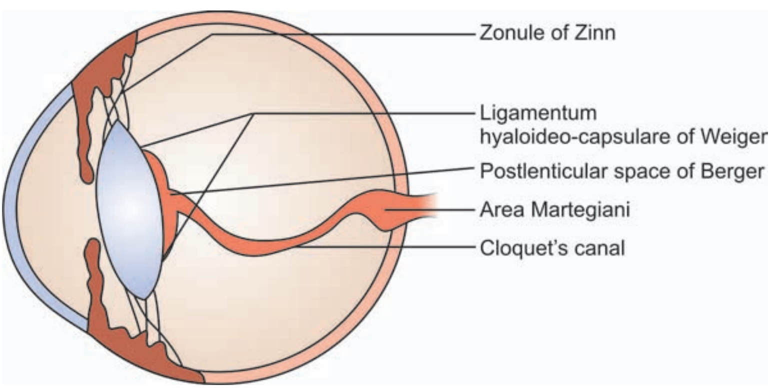


Fig. 1-13: Anatomical areas of the vitreous chamber

From developmental point, vitreous is divided into 3 parts:

i. Primary vitreous— From the posterior pole of the lens to the optic disc is a space called Cloquet's/Stilling's/hyaloid canal (Fig. 1-13) containing remnants of the primary vitreous.
ii. Secondary vitreous— It fills the vitreous chamber.
iii. Tertiary vitreous— The zonules of Zinn represent tertiary vitreous.

BLOOD SUPPLY OF EYEBALL

ARTERIAL SUPPLY

The eyeball is supplied by the branches of the ophthalmic artery, which is a branch of the internal carotid artery. Ophthalmic artery enters orbit through the optic foramen and divides into two sets of vascular system. The retinal vasculature, i.e. central retinal artery supplies inner half of the retina, whereas the ciliary system formed by other branches supply the uveal tract, the outer half of the retina and the optic nerve. The branches of ophthalmic artery are:

i. Central retinal artery: It enters the optic nerve 15–20 mm behind the eyeball. It divides at or just posterior to the surface of the optic disc into two main trunks superior and inferior. They again subdivide into superior and inferior temporal and nasal arterioles which are located within the nerve fibre layer of the retina. These retinal arterioles are end arteries and each supply a quadrant of the retina. The capillaries on the surface of the optic disc are derived from these retinal arterioles.
ii. Short posterior ciliary arteries (20 in number)— They pierce the sclera in the ring around the optic nerve and form the circle of Zinn. They enter the uveal tract and divide into smaller vessels to form the vessels of the choroid and choriocapillaries.
iii. Long posterior ciliary arteries (2 in number)— They pierce the sclera on either side of the optic nerve and pass through the suprachoroidal space in horizontal location to reach ciliary body. Now, each artery divides into two branches and the two branches again anastomose with each other and anterior ciliary arteries, at the base of the iris to form "major arterial circle of iris" (Fig. 1-14).

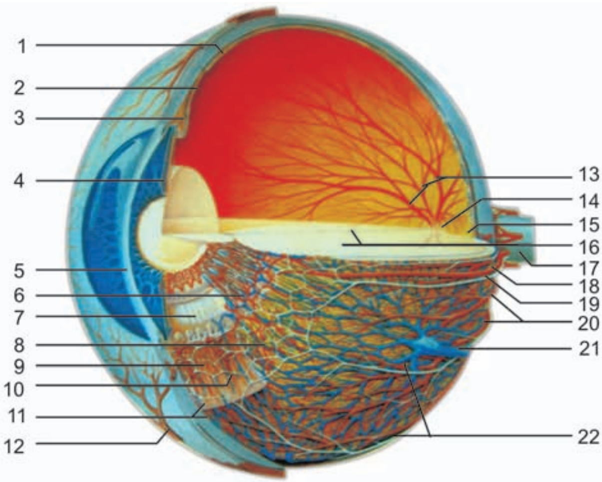
iv. Anterior ciliary arteries (7 in number)— They are the terminal branches of muscular branches of the ophthalmic arteries. They enter the eyeball through rectus muscles (two for each recti, except lateral rectus which has only one). They pierce the sclera 5 to 6.5 mm from the limbus and contribute to the formation of ''major arterial circle of iris''.

v. Recurrent meningeal artery

vi. Lacrimal artery

vii. Numerous recurrent arteries.

Twigs from the major arterial circle run radially into the iris and form a circular plexus of anastomosis at the collarette near the pupillary margin, called "minor arterial circle of iris" (Fig. 1-14).



1 = Retina, 2 = Orbiculus ciliaris, 3 = Ciliary body with ciliary muscle meridional and circular fibres, 4 = Iris with dilator pupillae muscle and sphincter pupillae muscle, 5 = Cornea, 6 = Minor and major arterial circle of iris, 7 = Zonular fibres, 8 = Ora serrata, 9 = Ciliary body with ciliary muscle meridional and circular plexus, 10 = Ciliary plexus, 11 = Choroid, 12 = Anterior ciliary arteries, 13 = Retinal blood vessels, 14 = Optic disc, 15 = Macula lutea, 16 = Corpus vitreum with canalis hyaloideus, 17 = Optic nerve, 18 = Long posterior ciliary arteries, 19 = Long ciliary nerve, 20 = Short posterior ciliary arteries, 21 = Vortex vein and 22 = Short ciliary nerve

Fig. 1-14: Vascular supply of the eyeball

VENOUS DRAINAGE

It occurs through:

i. Vortex veins— Majority of venous drainage occurs through the tributaries of 4 vortex veins, which enter the sclera just behind the equator and pass obliquely through it. They drain into ophthalmic veins.

ii. Anterior ciliary veins – They drain blood from the outer part of the ciliary muscle and the ciliary body via ciliary venous plexus.

iii. Short posterior ciliary veins – They drain blood away from the sclera.

iv. The retinal veins – The 4 tributaries that correspond roughly to the branches of the central retinal artery unite at or just behind the optic disc to form the central retinal vein. The central retinal vein usually drains into cavernous sinus, after giving a branch to the superior ophthalmic vein. It may drain into the superior ophthalmic vein occasionally.

The major branches of the central retinal artery and tributaries of central retinal vein are located within the nerve fibre layer of the retina. In most of the retinal area two groups of capillary network exist. The superficial one is located within the nerve fibre layer, whereas the deep one is located between the outer plexiform layer and inner nuclear layer.

It is easy to distinguish the retinal arteries from the veins. The arteries are narrower (3/5th of the veins), bright red in colour with a well-defined light streak along their lumen. The veins are wider and less bright in colour. Retinal venous pulsation is physiological and is seen in significant number of people. Retinal arterial pulsation is pathological and is seen in glaucoma, aortic incompetence, etc.

CHAPTER

2

Anatomy of Appendages of the Eyeball

CONJUNCTIVA

It is a thin mucous membrane which attaches eyelids to the eyeball. It covers inner surface of the eyelids and reflected to cover anterior part of the sclera upto the limbus (Fig. 2-1).

REGIONS OF CONJUNCTIVA

a. Palpebral
   i. Marginal
   ii. Tarsal
   iii. Orbital.
b. Fornix
c. Bulbar
d. Limbal.

STRUCTURE

It consists of:

Epithelium

Marginal and limbal parts are lined by stratified squamous epithelium. The tarsal and orbital parts are lined by 2 layers of epithelium. The deeper layer is composed of cubical cells and superficial one is of cylindrical cells. At the fornix, often a 3rd layer of polyhedral cells is encountered between the 2 layers. But the tarsal conjunctiva of lower eyelid is composed of 3-5 layers of cells. From the fornix to the limbus more layer of cells are added between the superficial cylindrical and deep cubical cells. Goblet cells, i.e.

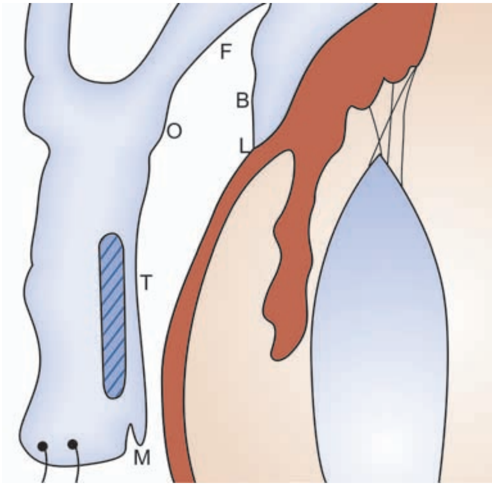


Fig. 2-1: Cross section through the upper eyelid and conjunctival sac showing
Different regions of conjunctiva

M = Marginal   T = Tarsal   O = Orbital
F = Fornix   B = Bulbar   L = Limbal

mucin secreting cells are found in all regions of conjunctiva, particularly more concentrated around the fornices.

Substantia Propria

It consists of:

i. Superficial adenoid layer consisting of fine connective tissue meshwork containing lymphocytes which is most developed in the fornices.
ii. Deeper fibrous layer.

EYELIDS

FUNCTIONS

a. Protection of eyeball from injury.
b. Protection of eyeball from excess exposure to light, thereby regulates the entry of light through pupil.
c. Swabs the tear film over the cornea by the process of blinking.

d. Drainage of tear through lacrimal system by pumping effect of lids on the lacrimal sac during blinking.
e. Emotional reactions.

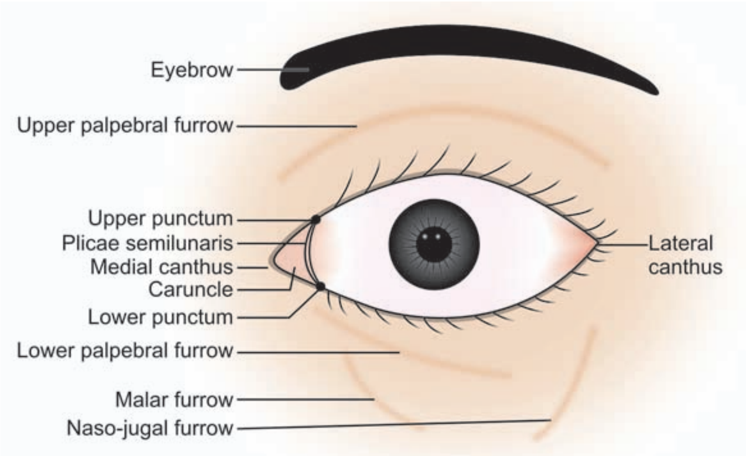


Fig. 2-2: Surface anatomy of the eyelid

Palpebral aperture or fissure measures about 11–12 mm × 28 mm in elderly and 14–15 mm × 28 mm in adults. The lateral canthus is about 2 mm above the plain of the medial canthus (Fig. 2-2). Caruncle is a small area of skin containing glands which opens into fine hair follicles. Plicae Semilunaris is a crescentic fold, just lateral to the caruncle and represents 3rd eyelid, i.e. nictitating membrane of lower vertebrates. Normal blink rate is 12-20/minute.

LID MARGIN

Both upper and lower eyelid margin is 2 mm broad, has a rounded anterior border and a sharp posterior border. The lacrimal puncta divides it into medial smaller lacrimal part and larger lateral ciliary part. The lacrimal part is devoid of any eyelashes and tarsal glands. Just in front of posterior border lies a row of small openings of tarsal glands. Just in front of these openings, a thin grey line can be seen, where the eyelid can be easily separated into 2 distinct layers (Fig. 2-3).

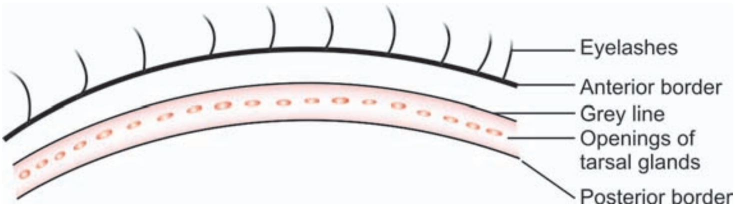


Fig. 2-3: Free margin of eyelid (Intermarginal Strip)— Schematic drawing. Structure of the eyelids—The layers of the eyelids are seen from before backwards are described (Fig. 2-4):

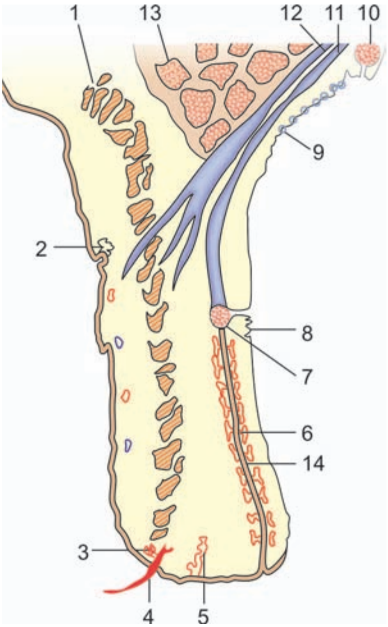


Fig. 2-4: Section through the upper eyelid (schematic). **1** = Orbicularis oculi, **2** = Sweat gland, **3** = Gland of Zeis, **4** = Eyelash, **5** = Gland of Moll, **6** = Meibomian gland, **7** = Gland of Wolfring, **8** = Crypts of Henle, **9** = Goblet cells, **10** = Gland of Krause, **11** = Müller muscle, **12** = Levator palpebrae superioris , **13** = Fat and **14** = Tarsal plate.

a. *The skin:* It is very thin, elastic, having folds and practically without hairs.
b. *The subcutaneous tissue:* It consists of loose areolar tissue devoid of any fat.

c. *The layer of striated muscle:* Muscle fibres of orbicularis oculi are arranged concentrically around the palpebral fissure. Muscle of Riolan is a part of this muscle which lies adjacent to whole thickness of the lid margin.

d. *The submuscular connective tissue:* It is similar to the subcutaneous tissue. It represents the grey line of the eyelid margin, i.e. through this plane the eyelid can be easily split into 2 distinct portions. Fibres of levator palpebrae superioris (present only in the upper eyelid) traverses through this layer. Some of the fibres pass through the orbicularis fibres to be attached to the skin to form the superior palpebral furrow. Residual fibres are attached to the lower-third of the tarsal plate anteriorly.

e. *The fibrous layer:* It consists of:
   i. *Tarsal plate:* The central thick portion present in both the eyelids forming the skeleton of the eyelids.
   ii. *Orbital septum:* The peripheral thin portion.

f. *The layer of non-striated muscle (muscle of Müller):* This muscle takes origin from levator palpebrae superioris (in the upper eyelid) and inferior rectus (in the lower eyelid). They are inserted into the attached border of the tarsal plates, i.e. upper border of superior tarsus and lower border of inferior tarsus.

g. *The palpebral conjunctiva:* This layer is firmly attached to the tarsal plates.

GLANDS OF THE EYELID

Meibomian Glands (or Tarsal Glands)

i. They are long sebaceous glands, located within the substance of tarsal plates and secrete sebum.
ii. They are arranged vertically parallel with each other.
iii. They extend from the attached margin to the free margin. So, they open into the eyelid margin as a single row of orifices (25 for the upper lid and 20 for the lower lid), just anterior to the posterior border (Figs 2-3 and 2-4).
iv. The sebaceous material secreted by these glands constitute the outermost lipid layer of precorneal tearfilm. It prevents overflow of lacrimal secretion and evaporation of underlying tear secretion.
v. It is also responsible for airtight closure of the eyelids. Thus, it also prevents maceration of the skin by the tear.

Glands of Zeis

i. They are also sebaceous glands and their ducts open into the follicles of the eyelashes directly (Fig. 2-4).
ii. They also secrete sebum and contribute to the outer lipid layer of the precorneal tearfilm.
iii. In addition, the secretion prevents the dryness and brittleness of the eyelashes.

Glands of Moll (or Ciliary Glands)

i. They are developmentally arrested sweat glands situated near the eyelashes.
ii. Their duct may open into either the duct of a gland of Zeis or between two eyelashes (Fig. 2-4).

Glands of Wolfring

i. They are accessory lacrimal glands of the upper eyelids.
ii. They are located in the region of the upper border of the tarsal plate.

Glands of Krause

i. They are also accessory lacrimal glands.
ii. They are located within subconjunctival areolar tissue of the fornices, mostly in the superior fornix.

LACRIMAL APPARATUS

The lacrimal apparatus consists of the following:

SECRETORY SYSTEM (LACRIMAL GLAND AND ACCESSORY LACRIMAL GLANDS OF KRAUSE AND WOLFRING – FIG. 2-5)

Lacrimal gland is lodged in the lacrimal fossa in the anterolateral part of the roof of the orbit and consists of larger orbital part and the smaller palpebral part, separated anteriorly by the aponeurosis of the levator palpebrae superioris muscle (LPS). 10 – 12 ducts from the orbital portion pass through the palpebral portion to open into lateral part of the upper conjunctival fornix. Also, 1 – 2 ducts open into lateral part of lower fornix. It is a tubuloracemose gland similar to parotid gland structurally.

Accessory lacrimal glands of Krause are located in the subconjunctival areolar tissue of the fornices, mostly in the superior. Accessory lacrimal glands of Wolfring are located in the region of the upper border of the tarsus of the upper eyelid.

DRAINAGE SYSTEM (LACRIMAL PUNCTA, CANALICULUS, COMMON CANALICULUS, LACRIMAL SAC AND NASOLACRIMAL DUCT – FIG. 2-5)

i. Lacrimal puncta are small oval openings situated on small elevations, one in each lid, 6 mm from the medial canthus at the junction of ciliary and lacrimal part of the lid margin.

ii. Lacrimal canaliculus, 2 in number, upper and lower, connects lacrimal sac with the lacrimal punctum. It consists of a vertical (2 mm) and horizontal portion (6–8 mm). Usually, each canaliculus opens separately into the lacrimal sac (2.5 mm below the apex). Occasionally, they join together to form common canaliculus before opening into the lacrimal sac. A mucosal fold present at this point to prevent reflux of tear is called “valve of Rosenmüller.”

iii. Lacrimal sac is lodged in the lacrimal fossa, formed by the lacrimal bone and the frontal process of the maxilla. Portion of the lacrimal sac above the medial palpebral ligament is called fundus. Distended lacrimal sac measures 15 mm in length and 5–6 mm in width. It is enclosed by lacrimal fascia. In the between lacrimal sac and the fascia lies a fine venus plexus.

iv. Nasolacrimal duct is the downward continuation of the lacrimal sac. It is 12–24 mm in length and 4 mm in diameter. It is lodged in a bony canal and passes backwards, laterally and downwards to open into the inferior meatus of the rose. Upper end of nasolacrimal duct is the narrowest portion. Several mucosal valves are described within the naso-lacrimal duct. All of them are simply mucous membrane fold without any valvular function except the valve of Hasner. “Valve of Hasner” is located at the lower end of the naso-lacrimal duct (Fig. 2-5).

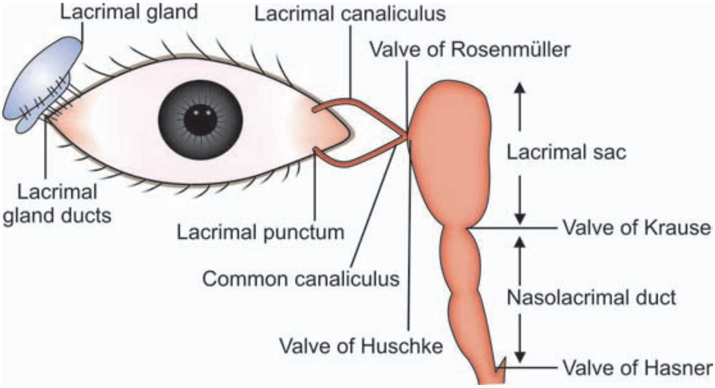


Fig. 2-5: Lacrimal apparatus

DRAINAGE OF LACRIMAL FLUID/TEAR

During the process of blinking tear fluid is drawn medially into the conjunctival sac. Most of the tear fluid (70%) enters lower lacrimal canaliculus through capillary action. Contraction of the preseptal orbicularis, present around the lacrimal sac, causes dilatation of the lacrimal sac. This creates a negative suction pressure to suck tear into the sac (lacrimal pump). The lacrimal sac contracts on opening of eyes and expels tear fluid into inferior meatus of the nose through nasolacrimal duct. Thus, tear is expelled from the sac into the nasolacrimal duct due to its elasticity and is aided by gravity.

MUSCLES OF THE EYE

Muscles of the eye are grouped as under:

a. *Intrinsic muscles:* These are muscles inside the eye and are discussed in the anatomy of the uveal tract. They are dilator pupillae, sphincter pupillae and ciliary muscle.
b. *Extrinsic muscles:* They are 6 in number.
   - Superior rectus
   - Inferior rectus
   - Medial rectus
   - Lateral rectus

- Superior oblique
- Inferior oblique.

ORIGIN

All the extrinsic muscles except inferior oblique have a common origin from the annular tendon of Zinn, around the optic foramen, at the apex of the orbit. Inferior oblique arises from a small depression just behind the inferior orbital margin, near the medial wall, close to the lacrimal fossa.

INSERTION

All the extrinsic muscle tendons are inserted into the sclera (Table 2-1) after piercing the Tenon's capsule.

Table 2-1: Distance of the insertion of the recti from the limbus

Extrinsic muscle	*Distance from the limbus (Insertion)*
Superior rectus	7.75 mm
Lateral rectus	7 mm
Inferior rectus	6.5 mm
Medial rectus	5.5 mm

Superior oblique muscle after origin passes forward to reach trochlea which is situated anteriorly between medial wall and roof of the orbit. Here it becomes tendinous and passes through the trochlea (or pulley) and turns backwards, laterally and downwards to pass below the superior rectus. It is inserted in the sclera obliquely above and lateral to the posterior pole.

Inferior oblique muscle after origin runs below the inferior rectus to insert in the sclera below and lateral to the posterior pole. Its insertion lies very close to the macula.

NERVE SUPPLY

All the muscles are supplied by the oculomotor (IIIrd cranial) nerve except the superior oblique which is supplied by the Trochlear (IVth cranial) nerve and lateral rectus which is supplied by the abducens (VIth cranial) nerve.

ACTIONS OF THE EXTRAOCULAR MUSCLES

All the extrinsic muscles except the medial and lateral rectus has a main and subsidiary action. The main action of a muscle will be greatest when the eye is looking in a certain direction. Here the subsidiary action will be least. Often during certain movements, two muscles act together. This is called synergistic action. For example, on looking directly downwards inferior rectus works synergistically with the superior oblique (Table 2-2).

Table 2-2: Actions of the extrinsic muscles of the eye

Muscle	*Main action*	*Subsidiary action*
Superior rectus	Elevation (Maximum in abducted position)	Adduction and intorsion (Maximum in adducted position)
Lateral rectus	Abduction	Nil
Inferior rectus	Depression (Maximum in abducted position)	Adduction and extorsion (Maximum in adducted position)
Medial rectus	Adduction	Nil
Superior oblique	Depression (Maximum in adducted position)	Abduction and intorsion (Maximum in abducted position)
Inferior oblique	Elevation (Maximum in adducted position)	Abduction and extorsion (Maximum in abducted position)

STRUCTURAL PECULIARITIES OF THE EXTRINSIC MUSCLES

a. Individual muscle fibres are very thin compared to other striated muscles in the body.
b. Rich supply of nerve fibres and rich supply of elastic fibres contribute to the delicate nature of the ocular movements.
c. Size of the nerve which supplies each muscle is much larger compared to the bulk of the muscle than those found in other parts of the body.
d. Origins of superior and medial rectus muscles are more adjacent to the dural sheath of the optic nerve. This anatomical fact is

responsible for associated pain in retrobulbar neuritis in extreme movements of the eyeball.

e. Superior rectus is the longest extrinsic muscle of the eyeball.
f. Inferior oblique is the only muscle which arises from the anterior part of the orbit.
g. All the extrinsic muscles of the eye are provided with fascial check ligaments which are intimately blended with the peri-muscular sheath and Tenon's capsule for controlling their delicate movements.

TENON'S CAPSULE (OR FASCIA BULBI)

It is a fibrous membrane which covers the eyeball from the limbus to the optic nerve. So, the cornea remains uncovered by this membranous capsule. The Tenon's capsule is attached to the eyeball, in front at the limbus, to the extrinsic muscles and to the sclera by fine trabeculae. The posterior surface of this capsule is in close contact with the orbital pad of fat. The lower part of the Tenon's capsule is very thickened to form a hammock to support the eyeball. This thickened part is called suspensory "ligament of Lockwood". The Tenon's capsule is pierced by:

i. Anteriorly – 6 extrinsic muscles
ii. Posteriorly – Optic nerve, ciliary nerves and arteries
iii. At the equator – Vortex veins.

LEVATOR PALPEBRAE SUPERIORIS

It arises by a short tendon from the apex of the orbit, above and in front of the optic foramen. It's tendinous origin is blended with the origin of the superior rectus.

INSERTION

It ends in a membranous aponeurosis to insert as following slips;

i. Anterior slip—Main insertion is at the skin of the upper eyelid by passing through the orbicularis fibres.
ii. Central slip—Upper margin and anterior lower third of tarsal plate of upper eyelid

iii. Posterior slip— Superior fornix of the conjunctiva
iv. Medial horn/slip— To the medial palpebral ligament
v. Lateral horn/slip— It separates the orbital and palpebral part of the lacrimal gland and is attached to the lateral palpebral ligament.

NERVE SUPPLY

Oculomotor (IIIrd Cranial) nerve. Superior division of the IIIrd nerve innervates the muscle usually by traversing through the medial side of the superior rectus muscle.

ACTION

It elevates upper eyelid.

CHAPTER

3 Anatomy of the Orbit

INTRODUCTION

The orbits are pear-shaped cavities and act as sockets for the eyeball. It is formed by the following seven bones (Fig. 3-1):

i. Frontal
ii. Sphenoid
iii. Ethmoid
iv. Lacrimal
v. Palatine
vi. Maxilla
vii. Zygomatic.

It is of great importance to know the structures adjacent to the orbit. They are;

- Above—Anterior cranial fossa, frontal sinus
- Below—Maxillary sinus
- Medially—Nasal cavity and sinuses, ethmoid sinus
- Laterally (From behind forwards)—Middle cranial fossa, temporal fossa.

Volume of the orbit is 30 ml. Eyeball occupies only 20% of the orbital volume.

Medial walls of the orbits are parallel to each other, while the lateral walls are inclined at 90° to each other.

ROOF

It is very thin and very much vulnerable to penetrating injury through the upper lids. It presents fossa for the lacrimal gland and

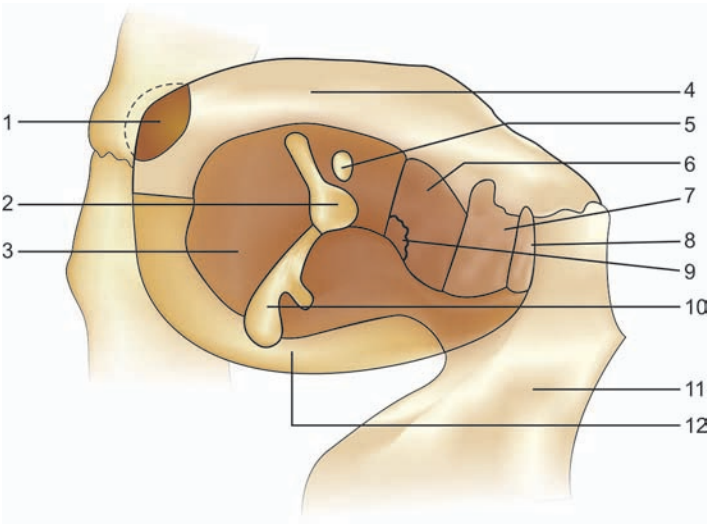


Fig. 3-1: Schematic drawing of bones forming the orbit
= Fossa for lacrimal gland, = Superior orbital fissure, = Greater wing of sphenoid, = Frontal bone, = Optic canal, = Ethmoid bone, = Lacrimal bone, = Lacrimal fossa (for sac), = Palatine bone, = Inferior orbital fissure, = Maxilla and = Zygomatic bone

the depression for the attachment of the trochlea for the superior oblique tendon.

MEDIAL WALL

It is the thinnest of the orbital wall. The part formed by the orbital plate of the ethmoid is as thin as paper (lamina papyracea). Fracture of the orbital part of the ethmoid by blunt injury is very common and it causes orbital emphysema by trapping of air escaped from the ethmoidal sinuses within the eyelids. It presents lacrimal fossa and bony nasolacrimal canal. Lacrimal fossa lodges lacrimal sac and is formed by the frontal process of the maxilla and the lacrimal bone. It is bounded anteriorly and posteriorly by the anterior and posterior lacrimal crest respectively. Lacrimal bone separates ethmoidal air cells in the upper half of the fossa and middle meatus of the nose in the lower half. Inflammation of the ethmoidal sinus spreading to orbit is also very common probably due to thinness of the medial wall.

FLOOR

It is the shortest of the orbital walls and separates maxillary sinus from the orbit.

LATERAL WALL

It is most exposed to external injuries. However, it is the thickest of the orbital walls providing protection from external injuries. Lateral to it lies temporal fossa and middle cranial fossa from anterior to posterior.

ORBITAL CONTENTS

- Eyeball
- Optic nerve
- Extrinsic muscles
- Lacrimal apparatus
- Adipose tissue
- Fascia bulbi (or Tenon's capsule)
- Nerves and vessels which supply the above structures.

SUPERIOR ORBITAL FISSURE (SPHENOIDAL)

It is a comma-shaped fissure between greater and lesser wings of the sphenoid bone. It is located between the roof and the lateral wall of the orbit. It is the largest communication between the orbit and the middle cranial fossa. The superior orbital fissure is divided into lateral and wider medial parts by the common tendinous ring. The lateral rectus arises from both margins of the fissure from this common tendinous ring. Structures passing through the superior orbital fissure are (Fig. 3-2):

a. Through the annulus, i.e. between the two heads of the lateral rectus muscle (from above downwards)
   i. Superior division of the oculomotor nerve
   ii. Nasociliary nerve
   iii. Inferior division of the oculomotor nerve
   iv. Abducens nerve.
b. Through the narrow lateral portion, i.e. above the annulus
   i. Lacrimal nerve
   ii. Frontal nerve
   iii. Trochlear nerve
   iv. Superior ophthalmic vein
   v. Recurrent lacrimal artery.
c. Through the wider medial portion – rarely, inferior ophthalmic vein.

INFERIOR ORBITAL FISSURE (SPHENOMAXILLARY)

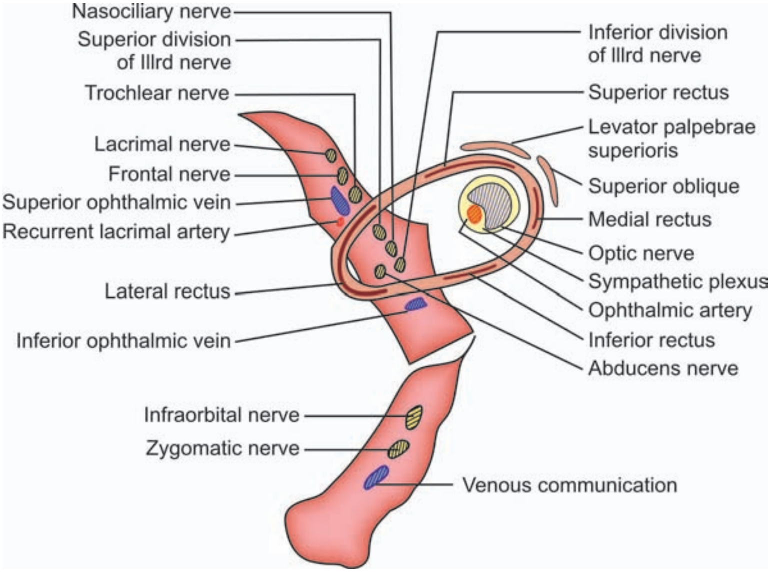
It is a fissure between greater wing of the sphenoid and the maxilla. It is located between the floor and the lateral wall of the orbit. Structures passing through it are (Fig. 3-2);

   i. Infraorbital nerve
   ii. Zygomatic nerve
   iii. Communication between the inferior ophthalmic vein and the pterygoid plexus.

OPTIC FORAMEN (OPTIC CANAL)

It is a canal formed by the two roots of the lesser wing of the sphenoid and communicates the apex of the orbit with the middle cranial fossa. The optic canal is separated from the wider medial part of the superior orbital fissure by a bar of bone. It is funnel-shaped with the orbital end being the mouth of the funnel. Structures passing through it are (Fig. 3-2);

   i. Optic nerve with its sheath, i.e. meninges
   ii. Ophthalmic artery embodied in the dural sheath of the optic nerve
   iii. Sympathetic plexus from the ophthalmic artery.



Schematic drawing of the orbital apex showing structures passing through the superior orbital fissure, inferior orbital fissure and optic canal

SURGICAL ANATOMICAL SPACES WITHIN THE ORBIT

Practically there are 4 spaces:

a. Subperiosteal space—The space between the bones of the orbital wall and the orbital periosteum (periorbita).
b. Peripheral orbital space—It is the space between the periorbita and the extrinsic muscles, which are joined by fascial connections.
c. Central space—It is the space bounded by the cone of the muscles, their fascial connections and the Tenon's capsule. It is also referred to as "muscle cone".
d. Tenon's space—The space between the globe and the Tenon's capsule.

Section 2

Physiology and Neurology of Vision

CHAPTER 4

Physiology of the Ocular Structures

AQUEOUS HUMOUR

It is a clear, colourless, transparent fluid that fills the anterior and posterior chambers of the eyeball.

FORMATION

It involves following mechanisms:

a. *Secretion:*
   - It accounts for 95% (approx.) of the volume of aqueous humour.
   - It is secreted by the cells of the ciliary epithelium of the ciliary processes by an active pump.
   - The active pump mechanism is responsible for 50 times higher concentration of ascorbate in the aqueous than in the plasma.

b. *Ultrafiltration:*
   - It is simply ultrafiltration through the capillaries in the ciliary processes.
   - The ultrafiltrates constitute the smaller particles and molecules from the blood, sparing the proteins.

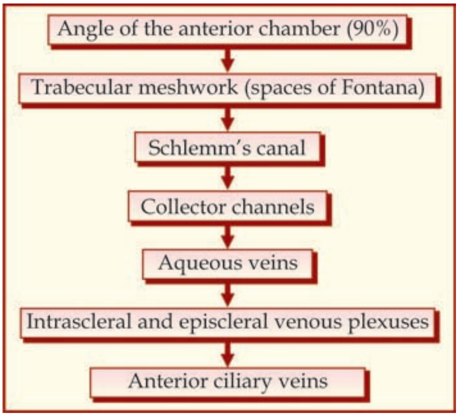
c. *Diffusion:* It is flow of certain ions along an electrochemical gradient.

However, aqueous thus formed is modified by metabolic activity of the cornea and the lens. This results in excess of lactic acid (from the lens) and a fall in glucose and bicarbonate level.

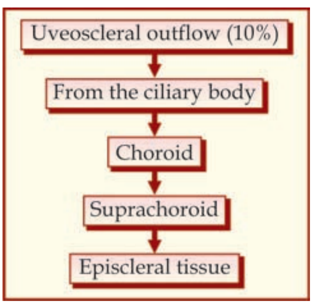
CIRCULATION

Once secreted and formed in the posterior chamber from ciliary body, it flows into the anterior chamber through the pupil (Fig. 4-1). It leaves anterior chamber through:

a. *Angle of the anterior chamber* (90%)



b. *Uveoscleral outflow* (10%)



FUNCTIONS

- It maintains intraocular pressure.
- It carries nutrients for the cornea, lens, vitreous body and the trabecular meshwork which are devoid of vascular supply.
- It is component of the optical system of the eye with the refractive index of 1.336.
- It removes waste products from the intraocular tissues.

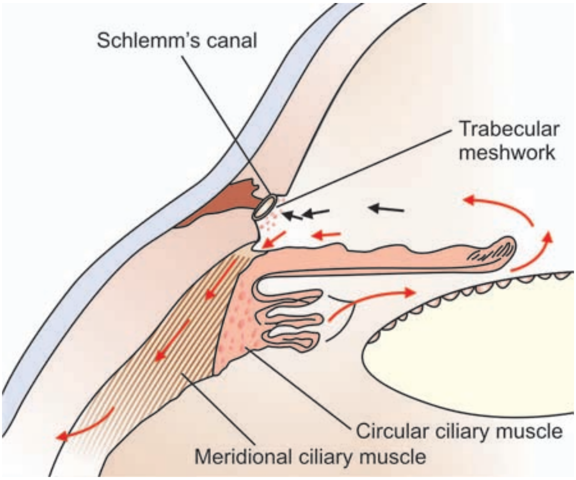


Fig. 4-1: Circulation of aqueous humour
Black arrow = Through angle of the anterior chamber
Red arrow = Through the uveoscleral outflow

BLOOD AQUEOUS BARRIER

It is the barrier between the blood and the ocular cavity which consists of semipermeable membranes. It is formed by (Fig. 4-2).

a. *Anteriorly:* A two way traffic of fluid occurs through the walls of the capillaries of the iris, which have free access to the anterior chamber through crypts on the anterior surface and the spongy stroma.
b. *In the middle:* It is formed by both the epithelial layers of the ciliary body. Here the fluid traffic is essentially one way into the cavity i.e., posterior chamber and is responsible for circulation of the aqueous humour from the posterior chamber through the pupil into the anterior chamber.
c. *Posteriorly:* A two way traffic of fluid occurs through the walls of the retinal capillaries, Bruch's membrane and retinal pigment epithelium. However, here the blood aqueous barrier is impermeable to large sized molecules. However, high lipid soluble particles cross this barrier easily. Increase in permeability of the capillaries will result in a aqueous humour

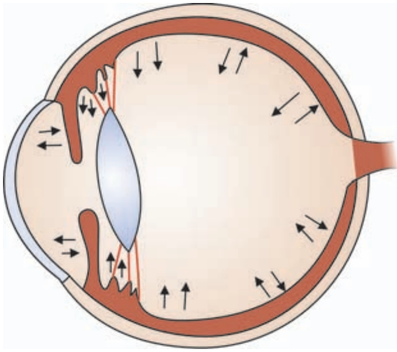


Fig. 4-2: Blood aqueous barrier

rich in protein rendering a turbid appearance called "Plasmoid Aqueous". Plasmoid Aqueous occurs in following situations;

i. Inflammation like iridocyclitis, cyclitis.
ii. Sudden lowering of intraocular pressure

↓

Mechanical stretching of the walls of the capillaries

↓

Increased permeability of the capillaries

VITREOUS HUMOUR

COMPOSITION

It is quite similar to aqueous humour. However, it contains greater amount of collagen, hyaluronic acid and acidic glycoprotein. Water content of vitreous is 98.5%. Bicarbonate content is less than in the aqueous humour.

It consists of a delicate meshwork of collagen fibrils embedded in water, hyaluronic acid and vitreous cells (hyalocytes). These hyalocytes, present only in the cortical area, produce hyaluronic acid and posses phagocytic property. The fibrillar meshwork is more dense at the periphery, i.e. cortical area than the centre.

There is presence of an active transport pump probably located in the ciliary body and retinal pigment epithelium to actively transport materials out of the vitreous. Most of the metabolic activity of the vitreous is confined to the cortical area.

CORNEA

Cornea requires a constant supply of oxygen and other essential metabolites, e.g. glucose, vitamins and amino acids to perform its vital function.

COMPOSITION

- Water 75–80%
- Electrolytes—Electrolyte level varies in different layers
- Collagen—It is destroyed by the enzyme collagenase
- Soluble protein—Albumin glycoprotein
- Immunoglobulins—IgG, IgA and IgM
- Glycosaminoglycans (GAG)—It is highly concentrated in the stroma than in the epithelium and endothelium. It is present in the interfibrillary space. Keratan sulphate, chondroitin sulphate and chondroitin are the three fractions of GAG found in the cornea
- Glycoprotein.

NUTRITION SOURCE

a. Oxygen from the air via diffusion across tearfilm
b. Glucose and amino acids from
   i. Aqueous humour
   ii. Perilimbal capillaries
c. Tearfilm.

METABOLISM

Cornea requires energy for renewal of tissues and maintenance of transparency. Energy is derived in the form of ATP (Adenosine Triphosphate) from anaerobic glycolysis (glucose metabolism). Metabolism is a process in which nutrients are converted into energy by a process of biochemical reactions, to be used by the cells for viability. Most of the metabolic activities occur at the level of the epithelium and endothelium. The metabolic pathways in cornea for generation of ATP, through glucose are following:

a. Anaerobic glycolysis (or Embden—Meyerhof pathway)—This is essentially an anaerobic pathway and accounts for majority of corneal metabolism. In this pathway, glucose is first oxidised to pyruvate and then subsequently reduced to lactate. This gives a net yield of two molecules of ATP. This pathway is most active in the corneal epithelium.

b. Tricarboxylic acid (or TCA/Kreb's cycle)—This is essentially an aerobic pathway and results in a net yield of 36 molecules of ATP (greater energy yield). This pathway is most active in the endothelium for greater energy requirement.
c. Hexose monophosphate shunt (or Pentose phosphate shunt)—This pathway plays a significant role in both the epithelium and the endothelium. It gives a net yield of 6 molecules of ATP.

Anaerobic glycolysis (Embden-Meyerhof pathway) accounts for the majority of glucose metabolism in cornea.

CORNEAL TRANSPARENCY

Cornea maintains high level of transparency to transmit more than 90% of incident light. Several factors contribute to the corneal transparency.

Structural

a. Epithelial
   i. Uniform regular arrangement of epithelium
   ii. Homogenous refractive index throughout the epithelium
   iii. Presence of precorneal tearfilm
   iv. Tight junctions between superficial epithelial cells.
b. Stromal
   i. Regular crystalline lattice arrangement of corneal collagen fibrils (Fig. 4-3), in a mucopolysaccharide ground substance, separated by less than the wavelength of light (Maurice Theory)
   ii. Absence of blood vessels
   iii. The diameter of the corneal collagen fibrils are smaller than the wavelength of light and therefore, do not interfere with the light transmission (Goldman and Benedek Theory)
   iv. Demyelination of corneal nerves.
c. Endothelial
   Uniform regular arrangement of endothelial cells.

Deturgence (Relative Dehydration)

Relative dehydration of stroma which is responsible for maintenance of normal corneal thickness is maintained by following structures:

i. Epithelium offers high resistance to flow of ions and water

ii. Endothelium
- Water imbibes into corneal stroma, but it is driven out by metabolically driven pump, i.e. Na–K ATPase pump of the endothelium.
- Zonulae occludentes, i.e. focal tight junctions of the adjacent endothelial cells maintain barrier to intercellular fluid traffic.

iii. Stromal deturgence
- Water is driven out of the stroma by negative imbibition pressure of the stroma
- Glycosaminoglycans (GAG) present in the corneal stroma act as a sponge to suck in water. However, in a normally dehydrated cornea they offer high resistance to inflow of water.

Corneal epithelium is permeable to lipid soluble substances. Corneal endothelium is permeable to water soluble substances.

Intraocular Pressure

High intraocular pressure will give rise to epithelial oedema, i.e. increased corneal thickness and loss of transparency. This is accentuated by endothelial damage.

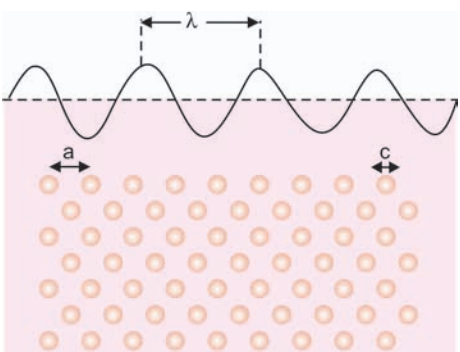
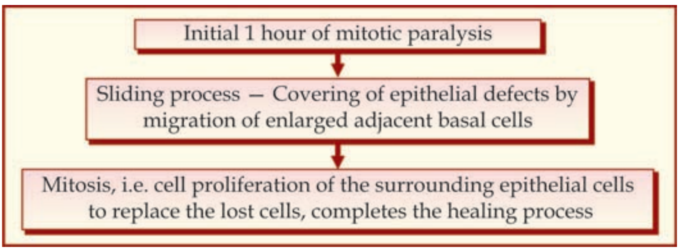


Fig. 4-3: Cross section view of lattice arrangement of collagen fibrils a < λ, c < λ,
a = Space between the collagen fibrils
c = Diameter of the collagen fibrils
λ (Lambda) = Wavelength of light

CORNEAL WOUND HEALING

Corneal wound healing is very essential to maintain transparency of cornea for clear vision. Corneal healing process is quite different from other tissues due to avascularity. It also varies according to site, suture material, nature of injury and topical ophthalmic preparations. It is discussed at various levels.

a. Epithelial level—Corneal epithelial repair is a complex interaction between the cells and the extracellular matrix. The process is supported by a variety of growth factor. It involves following phases:



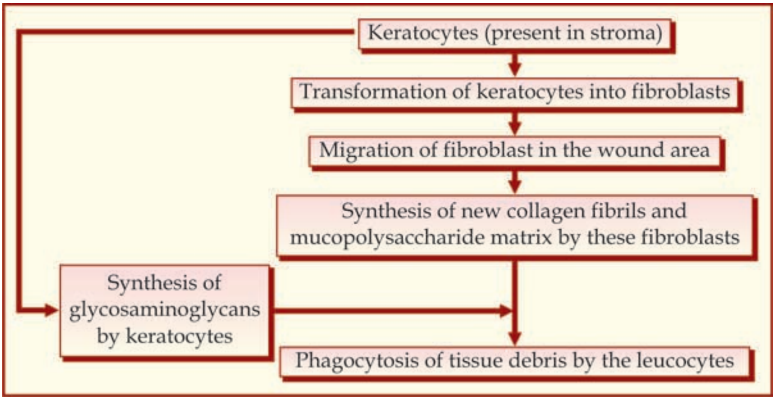
A variety of growth factors, which are secreted by various sources regulate the process of epithelial migration and mitosis. The following growth factors have been implicated in the corneal wound healing response:

i. Epidermal growth factor (EGF)
ii. Transforming growth factor beta (TGFβ)
iii. Fibroblast growth factor (FGF).

Regeneration of the corneal epithelium depends highly on the integrity of limbal stem cells. A certain percentage of limbal basal epithelial cells posses stem cell property, i.e. poor differentiation, long life, property of several rounds of self-renewal at shorter period.

b. Bowman's membrane level—Bowman's membrane doesn't regenerate.

c. Stromal level—Central avascular stromal wound takes longer time to heal than the peripheral wound. It involves following cascade of wound healing process.



d. Descemet's membrane level—Descemet's membrane easily regenerate from endothelial cells. It is essentially the basement membrane of the endothelial cells.
e. Endothelial level—Proliferation of endothelial cells by mitosis is restricted only to younger group of peoples. In adults the endothelial cells simply undergo enlargement and sliding to cover the defects.

LENS

The fluid traffic in the crystalline lens is controlled by the semi-permeability of the lens capsule and the subcapsular epithelium lining the anterior capsule.

NUTRITION SOURCE

a. Carbohydrates from the aqueous humour
b. Oxygen from the aqueous humour.

METABOLISM

Metabolic activity of the lens is mainly attributed to the cortex, the younger component. The lens requires energy in the form of ATP from carbohydrates through:

a. Anaerobic glycolysis [or Embden–Meyerhof pathway–80% of glucose]—in phakic eye lactic acid is found in significant amount as an end product of anaerobic glycolysis
b. TCA/Kreb's cycle—3% of glucose
c. Sorbitol pathway—It is relevant only in diabetic and galactosemic patients
d. Hexose monophosphate pathway—10% of glucose.

Hexose monophosphate pathway produces RNA and reduced nicotinamide adenine dinucleotide phosphate (NADPH) which is essential for reduced state of glutathione. Reduced glutathione maintains integrity of proteins complexes of lens membrane and is absent in cataracts. Active transport of ions takes place between the lens and the aqueous humour by an active Na–K–ATPase pump located in the subcapsular epithelium. It expels Na^+ and accumulates K^+ . So, the lens becomes the least hydrated structure of the body. The lens epithelium also actively transports amino acids essential for synthesis of new lens fibres.

COMPOSITION

a. Water—66%
b. Protein—33%.
   i. Soluble proteins (85%)—Mainly in the lens cortex— α, β and γ crystalline
   ii. Insoluble proteins (15%)—Mainly in the lens nucleus.

Lens is the least hydrated (66%) structure of the body and it is also the structure with the highest concentration of the protein (33%) in the body.

TEARS

It is the clear watery fluid secreted by the lacrimal gland which along with the secretions from the meibomian glands, the gland of Zeis, and Moll, the goblet cells and the accessory lacrimal glands of Krause and Wolfring helps to maintain the cornea and the conjunctiva moist and healthy. Precorneal tearfilm is composed of the following layers (Fig. 4-4):

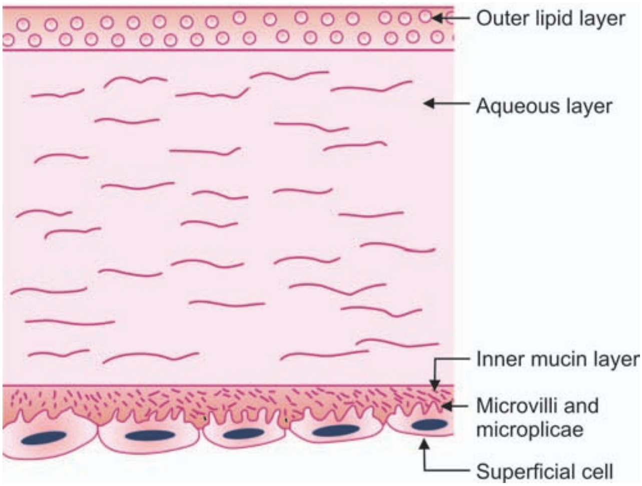


Fig. 4-4: Layers of the tearfilm

a. *Outer lipid/oily layer:* This layer is formed by secretions from the meibomian glands, glands of Moll and glands of Zeis.

Function

- It prevents evaporation of the aqueous layer of the tearfilm
- It provides lubrication between the eyelids and the cornea.

b. *Intermediate aqueous layer:* This layer forms the main bulk of the tearfilm and is secreted by the accessory lacrimal glands of Krause and Wolfring. They form the basal tear or normal lacrimation. Reflex tears are the result of excessive lacrimation from the lacrimal gland

Function

- It provides most of the bactericidal lysozymes, lactoferrins and other proteins
- It flushes debris from the conjunctival and the corneal surface
- It provides nutrition to the cornea.

c. *Inner mucin layer:* This layer is derived from the secretions of the conjunctival Goblet cells, Manz's glands and crypts of Henle.

Function

- It converts the corneal epithelial surface from the hydrophobic to a hydrophilic one.
- It helps to retain the aqueous layer.

Mucous or glycoproteins have a polar and a nonpolar end. The nonpolar end aligns with the hydrophobic epithelial cells and the polar end attracts water.

TEAR SECRETION

Basically two types of tear secretion exists:

a. *Basic tear secretion:* It occurs normally without any stimulation and it's source are accessory lacrimal glands of Krause and Wolfring. It is responsible for maintenance of moistness of cornea and conjunctiva. It is reduced in elderly people and in dry eye.

b. *Reflex tear secretion:* It occurs in response to an irritant, i.e. stimulation. It is also dependent on psychological (emotional) factors. It is produced mainly by the lacrimal gland.

Average rate of normal tear secretion is 30–120 μl (microlitre)/hour or 0.5–2.2 μl/minute. In young adults it is 2 μl/minute, whereas in elderly individual is 1 μl/minute.

COMPOSITION

- pH of tear varies between 7.3 and 7.7
- Osmolarity—Normal osmotic pressure is equivalent to 0.9% NaCl solution
- Water—98.2%
- Electrolytes—Na^-, Cl^-, Ca^{++}, Mg^{++}, K^+, HCO_3^-, Mn^+
  Sodium and chloride is present in high concentration.
- Vitamins—Vitamin A and Vitamin C
- Proteins—Lysozyme, Lactoferrin, Albumin and others. Total 60 types of proteins are present in tear. Lacrimal gland is responsible for production of lysozyme, lactoferrin, albumin. Albumin constitutes 60% of tear protein whereas, lysozyme constitutes 20–35%. Lysozyme destroys cell walls of many bacteria. So, it plays an important role in immune system of the eye.

- Immunoglobulins—IgA, IgG, IgM and IgE. Normally IgA and IgG are present in plenty and protect against infection. IgM is seen in severe infection. IgE is seen in excess in allergic situations.
- Cells—Include conjunctival, corneal keratinised epithelial cells, polymorphs, eosinophils and lymphocytes.
- Lipids—Cholesterol esters, fatty acids, free cholesterols, etc.
- Mucin (glycoprotein).

CIRCULATION OF TEAR

a. Evaporation (25%)
b. Lacrimal system (75%)—To nasal cavity
   i. Upper puncta (30–35%)
   ii. Lower puncta (65–70%).

CHAPTER

5

Physiology of Vision

INTRODUCTION

Rods and cones present in the retina serve as visual sensory nerve endings. So, when light falls upon the retina, the image of the object is focused on the retina by the dioptric system of the eye. Stimulation of these visual nerve endings by the light results in visual sensation. However, light falling upon optic disc doesn't give rise to any visual sensation due to absence of rods and cones. Therefore, it is called blind spot (of Mariotte). When light falls upon the retina, two essential reaction occur, photochemical and electrical changes.

PHOTOCHEMICAL CHANGES

It is initiated by the pigments present in the rods and cones. Rhodopsin is the pigment found in the rods with a peak absorption spectrum at 500 nm, and is responsible for night (scotopic) vision. Rhodopsin consists of a chromophore (11–cis retinal–a Vitamin A aldehyde) the reactive part and a protein called opsin. The bleaching of rhodopsin involves a complex chain of transformations. When light falls on the rods, it converts 11–cis retinal component to All–trans retinal (vitamin A) through several intermediaries (Fig. 5-1). This reaction is reversible in the dark, i.e. 11–cis retinal is again formed from All–trans retinal within the retinal pigment epithelium (Fig. 5-1). The photochemical changes initiate visual process and give rise to alteration in electrical potential, which are transmitted to the brain through the bipolar cells, ganglion cells and optic nerve successively. Lack of retinol may result in impaired dark adaptation, i.e. night blindness.

The cones have three pigments with spectral sensitivity peaks at 440, 540 and 570 nm. They are termed cyanolabe, chlorolabe and erythrolabe and are responsible for vision in bright light (photopic vision). Cones are also responsible for acuity of vision and colour vision.

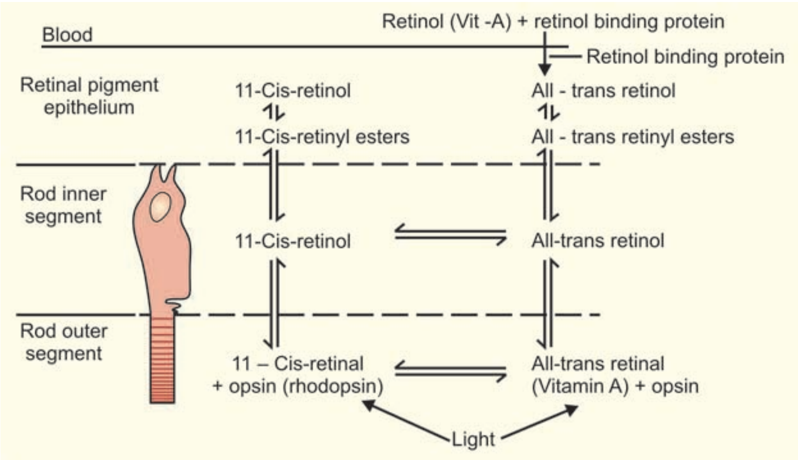


Fig. 5-1: Bleaching of rhodopsin and regeneration pathway

ELECTRICAL CHANGES

Based on the alteration in electrical potential which is initiated by the photochemical reactions, several electrophysiological tests are invented. These tests are clinically used to assess retinal integrity and it's connections to the brain. These are:

a. ERG (electroretinogram)
b. EOG (electrooculogram)
c. VER (visually evoked response).

ERG

It is the recording of mass electrical response of the retina following stimulation by light. It is recorded by placing one electrode in contact with the cornea (often via a contact lens). The second electrode is placed on the forehead.

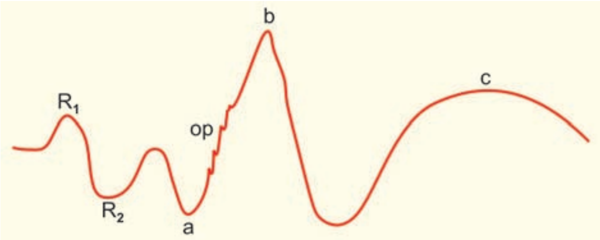


Fig. 5-2: Normal ERG response showing different components

Components of flash ERG wave (Fig. 5-2): The response is complex and consists of;

i. *Early receptor potential (ERP):* It is an initial rapid positive deflection R_1 and is followed by R_2 a negative deflection. It is a *cone generated potential*. It can be detected when the retina is stimulated with an intense flash of light 10^6 times brighter than the light stimulus required to elicit the ERG.

ii. *Late receptor potential:* A negative a wave which originates in the *photo receptors*.

iii. *A positive b wave:* which originates in the *bipolar and Müller cells*. Some low amplitude oscillatory potentials (op) are superimposed on this b wave originating from the *amacrine cells*.

iv. *A positive c wave:* Originates from the *retinal pigment epithelium*. Traditionally it is not measured.

The response varies according to dark or light adaptation, the colour of the stimulus and retinal health. Both a and b waves also have a photopic and scotopic component. It is possible to differentiate between functioning of the rods and cones. A rod dominated signal can be elicited by using low intensity flashes below the activation threshold of cone in a dark adapted eye. Similarly, a cone dominated signal can be elicited by using a bright flash of light in a low intensity white light background.

In pattern ERG, the signal consists of a positive potential followed by negative potential. This response originates from inner retinal layers with significant contribution from the ganglion cells. So, it is possible to assess functions of different layers of retina from our knowledge of different contributory layers to the component of the ERG wave.

A normal ERG signifies healthy retinal and choroidal circulation and healthy retinal tissues between the retinal pigment epithelium and the bipolar cells.

Types of ERG Response

i. Extinguished—Seen in functional failure of photoreceptors, i.e. rods and cones:
   - Retinitis pigmentosa
   - Occlusion of central retinal artery
   - Old total retinal detachment
   - Advanced siderosis bulbi

ii. Subnormal–Seen in situations where a considerable area of retina is suffering from loss of function.

iii. Negative–Seen in condition of gross disturbance of retinal circulation.

EOG (OR ARDEN TEST)

EOG is used for two distinct purposes:

a. It is used to monitor pattern of various characteristics eye movements, e.g. nystagmus.
b. It is more commonly used as a specific method for measuring the differences in electrical potential between the anterior (cornea) and posterior poles of the eye.

The corneal electrical potential is positive relative to the back of the eye. It is usually measured as a 60 mV potential difference. This is measured indirectly by placing two small disc electrodes on the skin on either side of the eye. The eye is rotated alternately right and left. The EOG signal will show a swing in amplitude of electrical potential. It becomes relatively negative as the eye rotates one way and then relatively positive as the eye rotates the other way. The EOG consists of two potentials:

a. *Standing or resting potential (or dark phase):* This procedure of signal is recorded at 1 minute interval for the first 15 minutes in the dark. During the dark phase the amplitude of the signal falls and reaches a trough. Standing or resting potential originates from the *retinal pigment epithelium*.

b. *Light potential (or Light rise):* Subsequently, the procedure is continued for a period of 15 minutes in a bright light environment.

During the light potential phase, the amplitude of signal rises slowly and reaches a peak. Light potential originates from the *photoreceptors*.

Clinically, the ratio between the light peak and the dark trough is assessed. It is also termed Arden Index or Arden Ratio. Normal Arden Ratio is 2:1. A low Arden Ratio (less than 1.7) indicates malfunctioning of the retinal pigment epithelium or photoreceptors from which the potential originates. A value between 1.7–1.8 indicates borderline malfunction.

Clinical Significance

a. It is used to diagnose objectively early stages of retinal diseases particularly of retinal pigment epithelium (RPE) and photoreceptors
b. It is used to diagnose retinal diseases specially in situations where fundus cannot be visualised.

VEP (OR VISUALLY EVOKED POTENTIAL/RESPONSE)

Light stimulation of the retina produces an electrical potential at the level of the occipital cortex. But, this response is of low amplitude and is buried in the background noise by the EEG activity. So, this VEP signal extraction requires repetition of the stimulus, and a computerised processing to cancel the background other spontaneous brain potentials. Two types of stimuli are used to record response from electrodes attached to the scalp over the occipital cortex.

a. Diffuse flash of light—A short duration flash from a xenon lamp.
b. Patterned stimulus, e.g. checker board—Pattern VER is particularly useful in estimating visual acuity in young, infants and children.

It is useful in infants and in uncooperative patients. It is independent of slight opacities of the media and refractive error.

VER is clinically used to measure:

i. Objective refraction

ii. Visual acuity
iii. Amblyopia
iv. Diagnosis of demyelinating diseases, e.g. multiple sclerosis.

VISUAL PERCEPTIONS (OR SENSATIONS)

Visual sensations result from stimulation of the retina by light and is of four varieties:

i. Light sense
ii. Form sense
iii. Sense of contrast
iv. Colour sense.

LIGHT SENSE

- Light sense is defined as the faculty which permits us to perceive light in all its gradations of intensity.
- Light minimum is at a point when light is just no longer perceived, if light falling upon the retina gradually decreased in intensity. The light minimum for fovea is higher than the other areas of the retina.

FORM SENSE

- Form sense is defined as the faculty which enables us to perceive the shape of an object.
- Cones are responsible for form sense. So, form sense is most delicate and acute at the fovea and falls off very rapidly towards the periphery.
- Form sense has also psychological component to perceive composite forms, e.g. letters in addition to the cone function.

Visual Acuity

Visual acuity is the measurement of spatial resolving capacity of the eye and is applied to central vision. There must be an unstimulated cone in between the two stimulated cones to allow for the resolution of two objects. The distance between two cones at the macular region is 0.004 mm and the object must subtend a visual angle of 1 minute at the nodal point of the eye to produce an image size of 0.004 mm. Based on this principle, distant visual acuity tests are developed.

Snellen's Chart

It is the most commonly used test for visual acuity. It consists of a rows of letters of diminishing size (Fig. 5-3). Each Snellen's letter is constructed in such way that it can be perfectly placed in a square which is further subdivided into 25 small squares. Each component part of the letter subtends an angle of 1 minute (1/60°) and the whole letter subtends an angle of five minutes of arc at the nodal point of the eye from a particular distance. The largest letter in a top row will subtend an angle of 5 minute at the nodal point if it is 60 metres from the eye. Hence, each row is assigned a specific number which indicates the distance in metres at which a person with normal visual acuity will be able to identify properly the letters (Fig. 5-4).

Snellen's chart have a single letter at top row and increasingly more letters of smaller sizes in lower rows. The test chart is illuminated by a lamp of 100 ft (foot candles) cs. The Snellen's chart is read from 6 metre or 20 feet distance.

Interpretation of visual acuity—

a. First note the lowest line which a subject can properly identify.

b. Visual acuity = $\dfrac{\text{Viewing distance}}{\text{Lowest identifiable line notation}}$

Thus, if a subject is able to identify upto row of letters on the "24" line from six metre distance, he has a visual acuity of 6/24 or 20/80. A visual acuity of 6/6 (or 20/20) is accepted as normal universally.

However, if a patient cannot identify the letter on the top row, his vision is < 6/60 and he is told to walk towards the acuity chart.

- If he is able to identify the letter of the top row at 3 metre distance, his visual acuity will be 3/60 and so on.
- If the patient cannot identify the letter even at 1 metre distance, he is asked to count the fingers of the examiner at 1 metre distance. If he is able to count fingers, his visual acuity is counting figures at 1 metre (CF 1m).

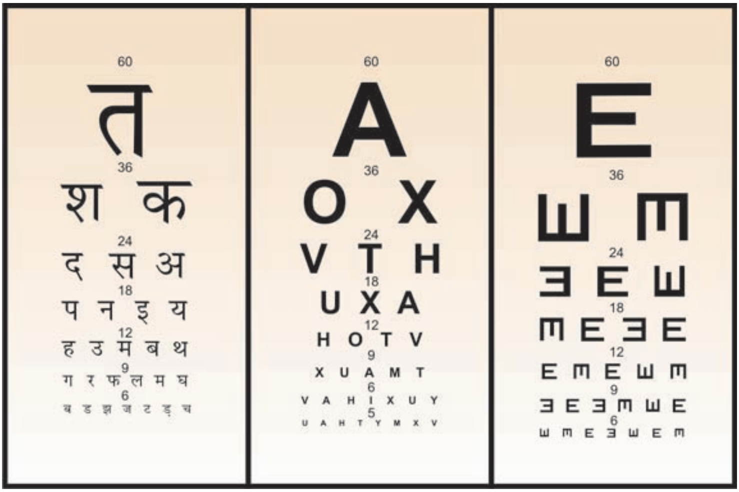


Fig.5-3: Snellen's distant test chart

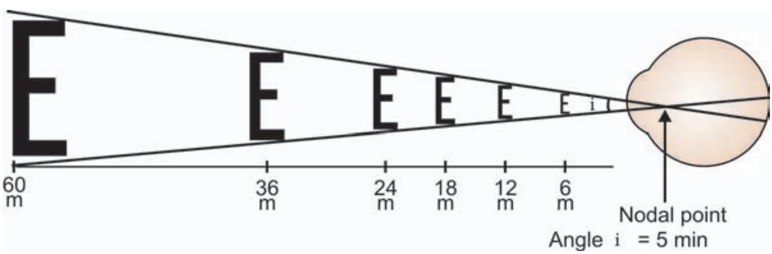


Fig. 5-4: Distance construction of Snellen's test chart

- If he can only identify the hand movement by the examiner, his vision is recorded as hand movements only (HM).
- If he is still unable to detect any hand movements, he is shifted to a dark room and light is shown on that eye (other eye is covered with palm of the hand) from 4 directions (up, down, right and left). He is asked to specify when the light is present and when it is absent. If he is able to perceive light in all directions, his visual acuity is recorded as perception of light present, projection of rays good (PL+, PR good).
- If his light perception is absent in any quadrant, it is recorded as PL+, inaccurate projection of rays in that quadrant.

- If he is able only to perceive light, his visual acuity is perception of light only (PL only).

In illiterate patients following two types of optotypes are used to replace the alphabets in Snellen's chart and visual acuity is interpreted on the same principle.

i. *Landolt ring:* It consists of a graduated series of ring, i.e. a circle with a break or gap in it. Conventionally the break is oriented in four direction—up, down, right or left in different optotypes. The subject is asked to identify the location of the break in each Landolt ring.

ii. *E chart (or Illiterate chart):* It consists of a chart with the graduated series of Snellen's letter "E" oriented in various directions, which the examinee is asked to identify, i.e. the direction to which the limbs of the "E" point (up, down, right or left).

Decimal Acuity

The Snellen's fraction can also be converted into a decimal number which is termed as decimal acuity or decimal notation. Thus, 6/6 (or 20/20) becomes 1.0, 6/12 (or 20/40) becomes 0.5 and 6/60 (or 20/200) becomes 0.1.

Minimum angle of resolution (MAR): It is expressed in minutes of arc. This is simply arrived at by inverting Snellen's visual acuity and converting it into a decimal number. So, a Snellen visual acuity of 6/60 (or 20/200) corresponds to 60/6, i.e. MAR of 10 min. of arc and a Snellen visual acuity of 6/12 (or 20/40) corresponds to MAR of 2 min of arc. Therefore, MAR in min of arc is also reciprocal of the value of the decimal acuity.

LogMAR (Logarithm of MAR): It is the basis of constant geometrical progression from one letter to the next in each line and from one line to the next line. The lines progress in 0.1 logMAR steps and each letter accounts for 0.02 score of each line. So, when the visual ecuity is 6/60 (or 20/200), the MAR is 10 min of arc. So, logMAR= $\log_{10}^{(10)}$ = 1.0. Similarly, visual acuity of 6/6 (or 20/20) corresponds to MAR of 1 and logMAR of $\log_{10}^{(1)}$, i.e. 0. If the patient's visual acuity is 6/12 (or 20/40) and he is able to read 3 letters in next line his logMAR will be = $\log_{10}^{(2)} + (3 \times 0.02) = 0.30 + 0.06 = 0.36$.

Bailey–Lovie visual acuity chart is the most common amongst the charts developed based on the logMAR scale. It consists of 5 letters in each row and geometric progression in the size and interval of the letters from one row to the next row, decreasing by a factor of $\log_{10}^{(10)}$. The letter sizes range from 6/60 (or 20/200) to 6/3 (or 20/10) in 14 rows (Fig. 5-5). The size of the letter in each row is 4/5th of the letter in upper row. Bailey-Lovie chart is more precise than a Snellen's visual acuity chart and most useful with low vision patients.

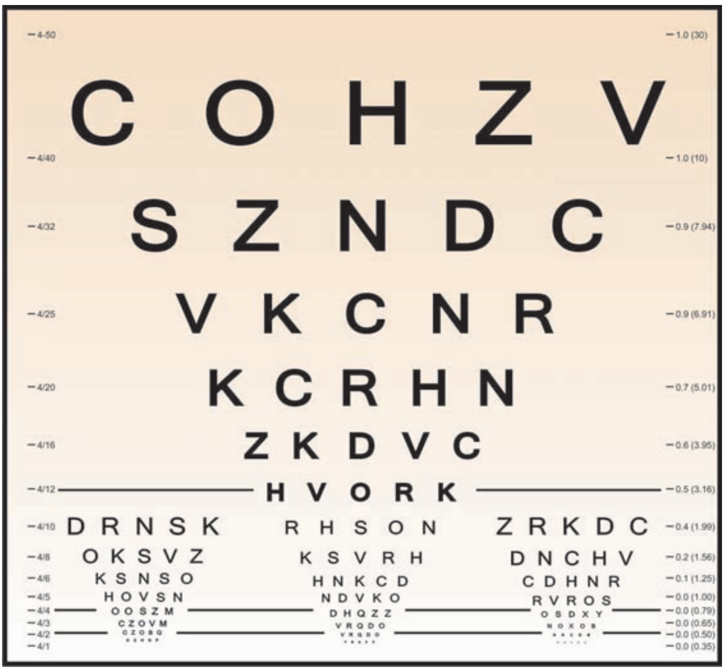


Fig. 5-5: Bailey-Lovie chart

Near Visual Acuity Test

Near visual acuity is tested at a standard distance of 40 cm and the size of the smallest print that can be read is interpreted as the near visual acuity.

Test Types

a. N system of notation—This is based on typesetters point system to specify size of the letters and Times Roman font is used. Each point equals 1/72 inch. Thus, N_6 letters measure 6/72 inches in height and N_8 letters measure 8/72 inches in height.
b. Jaeger notation—There is lack of uniformity in Jaeger's text print sizes progression. It is indicated by the letter J followed by a print size, e.g. J6, J8, etc.
c. Bailey-Lovie word reading chart—It is composed of words in Times Roman font and progression of size in each line in logarithmic. The range of size varies between 80 point and 2 point print.

Potential Visual Acuity Tests

These tests are used to predict and assess the visual acuity potential of eyes in situation where it is not possible to clinically examine the macula, e.g. cataract. Significant potential visual acuity indicates recovery of good visual acuity following cataract surgery. The following tests are employed:

i. Pin-hole test
ii. Bluefield entoptic phenomenon—It is the ability to identify moving white dots (representing white blood corpuscles in perifoveal capillaries) on diffuse illumination of retina by blue light. It indicates healthy macula.
iii. Potential acuity metre (PAM)—Here, a letter chart, usually Snellen's test chart is projected onto the retina through a small pin-hole.
iv. Laser interferometry—Laser light from two sources is projected onto the retina.

SENSE OF CONTRAST

- It is defined as the faculty which enables us to perceive contrast in luminance between regions which are not separated by definite margins.

- Contrast sensitivity is reduced in many diseases, e.g. cataract, optic neuritis, glaucoma, macular diseases, etc. whilst the visual acuity may be almost normal.
- Person requiring lot of contrast to see a target has lower contrast sensitivity.

Test of Contrast Sensitivity

Contrast sensitivity is assessed using a sine wave grating scale which consists of a gradual transition between alternating light and dark bands without definite edges, with the narrower bands having higher spatial frequency. The following tests are used based on sine wave grating:

a. Visitech chart
   i. It is tested at a distance of 3 metres for distance system and 40 cm for near system.
   ii. It contains circles of photographic plates arranged in 5 rows and 8 columns (total of 40 circles). Each circular plate contains a sine wave grating and the spatial frequency is different in each row with decreasing contrast sensitivity along the column. The sine wave gratings are either vertical or tilted 15° to the right or the left.
   iii. The patients are asked to identify the orientation of each grating.

b. Bailey-Lovie visual acuity chart
   i. It is tested at a distance of 4 metre
   ii. It contains 5 letters on each line and a logarithmic progression in size from one row to the other row (a total of 14 rows).

c. Pelli-Robson contrast test chart
   i. It is tested at a distance of 1 metre.
   ii. It consists of 8 lines of letters with 16 triplets of letters with a decreasing level of contrast in next letters to their background. Each line contains two triplets.
   iii. Letters of the triplets, i.e. of the same group have same contrast level.

COLOUR SENSE

- This is defined as the faculty which enables us to distinguish between different colours.
- Cones are responsible for colour sense and occurs only in photopic condition.
- There is existence of three types of pigments in different cones which are responsible for preferential absorption of wavelengths of light corresponding to red, green and blue colour.
- All other colours and white colour can be formed by their suitable proportional combination.
- An object is perceived as a coloured one when light rays of a particular wavelength are reflected from it to reach the retina.
- The normal colour vision is turned *trichromatic* and people with normal colour vision are called normal trichromats.

Theories of Colour Vision

a. Young–Helmholtz (or Trichromatic) theory—This theory assumes presence of three types of colour receptors, having preferential spectral sensitivities to red (570 nm), green (535 nm) and blue (440 nm). All other colours are perceived by a combination of these receptors.
b. Hering's theory—This theory assumes presence of three photochemical substances in the retina. These photochemical substances are broken down by white, red or yellow light and are responsible for initiation of different colour senses.
c. Opponent-colour theory—It is an updated version of Hering's theory. This theory assumes presence of three sets of receptor systems comprising antagonistic pair, i.e. red-green, blue-yellow and black-white. Stimulation of red light results in excitation of red in the receptor pair system and at the same time inhibition of green colour. Hering proposed a response in one direction for the colours, red, yellow and white and a response in the opposite direction for the opponent colours, i.e. green, blue and black. This theory explains well the colour sense including colour contrast and the colour blindness.

Currently colour vision perception is explained and is based on a combination of Trichromatic theory and Hering's opponent-colour theory. Trichromatic theory has it's origin at the retinal receptor level, while, the opponent theory results from the receptor outputs.

Colour Blindness

It is defined as significant departure of an individual's colour perception from that of an normal individual.

Aetiology and types:

a. Congenital

- Congenital defect in colour vision occurs due to absence of a cone pigment or a shift in spectral sensitivity of the cone pigment (Table 5-1).
- It accounts for majority of cases of colour blindness and is genetically inherited (Table 5-2) as sex linked disorder in which the defective gene is either on the X-chromosome carrying genes encoding for red and green pigments or chromosome 7 carrying genes encoding for the blue pigment.
- It affects mainly males who inherit the defective gene from their mother.
- It is very rare in females since they have to carry the defective genes on both the X-chromosomes.
- Defective colour vision occurs in 8% of male population and 0.5% of female population.
- It is stationary and stable in congenital type and affects both the eyes symmetrically.
- It is found in following genetic disorders:
  - i. Klinefelter's syndrome
  - ii. Turner's syndrome
  - iii. Glucose-6-phosphate dehydrogenase deficiency
  - iv. Haemophilia, etc.

Deuteranomaly is commonest and occurs in 5% of male and 0.3% of female population.

People with a colour defect of congenital origin are classified as in Tables 5-1 and 5-2.

b. Acquired

- This is relatively rare and mostly tritanopic, i.e. the blue colour sensation is missing.
- The defect may progress or regress and may be unilateral.

Table 5-1: Classification of congenital colour blindness

Types		*Colour response*
Anomalous Trichromats (indicates absence of red, green or blue cone function)	Protanomaly Deuteranomaly Tritanomaly	Partial red anomaly Partial green anomaly Partial blue anomaly
Dichromats (indicates a shift in the spectral sensitivity of the corresponding cone pigment)	Protanopia Deuteranopia Tritanopia	Red deficiency Green deficiency Blue deficiency
Monochromats	Cone monochromats (Atypical achromatopsia) Rod monochromats (Typical achromatopsia)	Normal visual acuity Diminished visual acuity, nystagmus photophobia

Table 5-2: Types of inherited colour vision defects with genetic inheritance

Types of colour defect		*Inheritance*
Anomalous Trichromats	Protanomaly Deuteranomaly Tritanomaly	X-linked recessive X-linked recessive Unknown
Dichromats	Protanopia Deuteranopia Tritanopia	X-linked recessive X-linked recessive Autosomal dominant
Monochromats	Cone monochromats (Atypical achromatopsia) Rod monochromats (Typical achromatopsia)	Unknown Autosomal recessive

- It occurs in following situations:
  i. Diseases of the cone, e.g. retinitis pigmentosa
  ii. Diabetic retinopathy
  iii. Glaucoma
  iv. Retinal/Macular disease
  v. Optic atrophy/optic neuritis/retrobulbar neuritis
  vi. Brunescent cataract
  vii. Drug induced, e.g. ethambutol, chloroquine, digitalis, oral contraceptives, chlorpromazine, streptomycin, etc.
- Red green colour defects are more common in diseases of the optic nerve whereas, yellow blue defect are more common in retinal diseases. So, acquired defect of colour vision is a sensitive early indicator of serious ocular and systemic diseases. Hence, monitoring of changes in status of colour vision often helps the clinician to assess improvement of the causative disorder. Distinguishing features between congenital and acquired colour defect are discussed in Table 5-3.

Table 5-3: Distinguishing features between congenital and acquired colour blindness

	Congenital	*Acquired*
Onset	Present since birth	Onset at a later age
Sex prevalence	Affects mostly male	Equal incidence
Progress	Stationary and stable	Progresses or Regresses
Involvement of eyes	Always both eyes	May be unilateral
Predominant types	Deuteranomaly	Mostly tritan
Visual acuity	Normal, except in Rod monochromats	Reduced
Treatment	Early detection and counseling	Treatment of causative disease

- Acquired colour defects may be classified as (Köllner's rule—1912);
  i. Red-Green defect—It is due to involvement of optic nerve and more proximal part of the visual pathway.

ii. Blue-yellow defects—It is due to involvement of ocular media, choroids and retina.

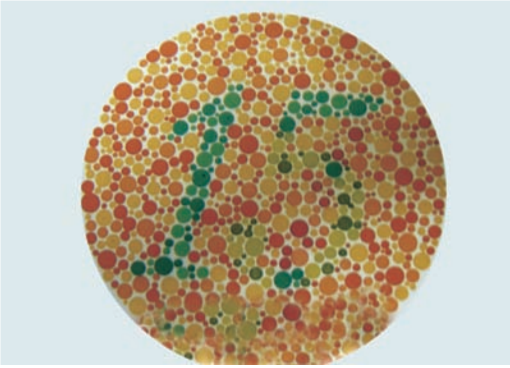
- A tritan colour defect is as a rule acquired, since inherited tritan defect is extremely rare.

Tests for Colour Blindness: Colour blindness is a disqualification for many occupations specially for drivers, pilots, physicians, etc. Colour vision testing should be undertaken for all at young age. Each eye should be tested separately for the colour vision.

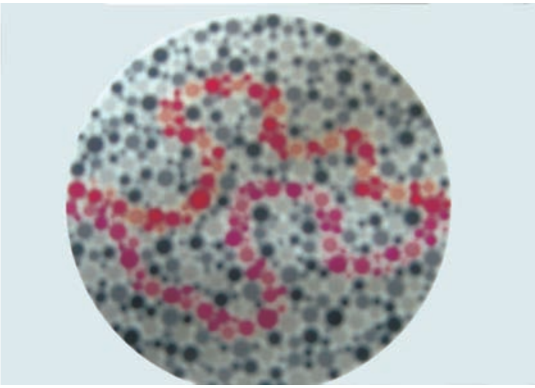
i. *ISHIHARA's pseudoisochromatic test plates:* It is a rapid and the most popular test and consists of lithographic plates on which dots of various sizes, colours, saturation and brightness are arranged so that dots of similar colour form a figure, e.g. a numeral or winding path among a background of dots of another colour (Figs 5-6A and B). An anomalous trichromat or a dichromat has difficulty in identifying the definite figure since it is indistinguishable from the background only by its difference in hue. The test also includes some plates in which the numbers can be identified by colour blinds (Fig. 5-6C), but not by the normal trichromats. These test plates mainly give an assessment of inherited red-green blindness (Figs 5-6A to C). The plates are held at 75 cm from the patient. The subject is allowed to observe each chart for a period of maximum 4 to 5 seconds. Care should be taken to avoid undue exposure of the plates to light to prevent fading of the colours.

ii. *Farnsworth Munsell 100 hue test:* It is a colour vision test consisting of 85 small discs made up of Munsell colours of equal chroma and value. The saturation of the colour is called "chroma" and brightness is termed "value" in this system. The patient is asked to arrange the small discs in a continuous and smooth series order. Errors are scored to arrive at a diagnosis of the type of colour defect. This test is useful for testing both inherited and acquired colour defect quantitatively.

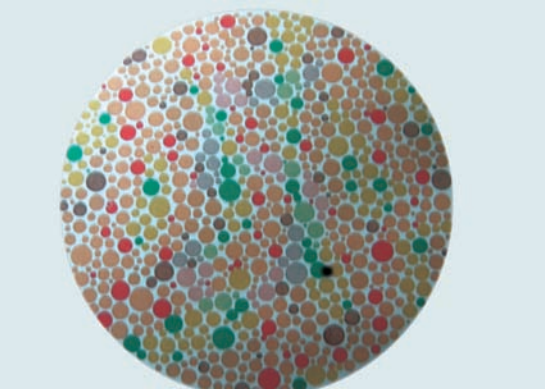
iii. *Farnsworth D–15 test:* It consist of only 15 small discs of Munsell colour. It is a more rapid test and miniature version of the Farnsworth Munsell 100 hue test.



A. Numeral



B. Winding path



Figs 5-6A to C: ISHIHARA's pseudoisochromatic test plates

iv. *Edridge-Green Lantern test:* This was usually employed for railway workers and coastguards. The test is performed in a dimly lit room with the examinee seated 6 metre (or 20 feet) apart from the lantern. Various colours are shown through an aperture by rotating a coloured disc. The size of the aprture can be varied and the intensity of the illumination can also be varied to simulate various weather conditions.

v. *Holmgren's wool test:* The patient is asked to make a series of colour matches from a collection of coloured wools of different hue.

vi. *Nagel's anomaloscope:* This is the *most accurate test* and fair amount of skill on the part of the examiner is essential. The examinee is asked to look through a telescope to observe a bright disc divided into two halves through a horizontal line. Yellow coloured light in one half is to be matched by a mixture of red and green colour in the other half by turning knobs.

Management of colour blindness:

Early detection and proper counselling: Early detection of colour blindness is essential since individuals with colour blindness are often unaware of this defect. Often, it is detected during pre-employment check-up and before admission to certain professional courses. When faced with this fact, the patient is often aggressive and unable to accept that this defect may bar him from his desired professional employment/study. So, early detection of this defect and suitable counselling regarding future career option is vital.

Supportive management:

i. In inherited red-green colour defects—Congenital colour blindness is incurable. However, use of certain aids may allow recognition of colours in congenital red-green colour blindness. Use of X-chrom/ChromGen contact lens or specially tinted spectacle lens allows recognition by increasing brightness of light of certain wavelengths and suppressing lights of certain wavelengths to create a difference in luminosity. X-chrom lens (trade name) is a dyed corneal hard contact lens whereas chromGen lens (trade name) is a tinted soft contact lens. They are usually fitted on the nondominant eye or on both the eyes. They enhance colour perception, specially in red-green defect of colour vision.

ii. In inherited rod monochromats—In congenital rod monochromats, i.e. achromatopsia with diminished visual acuity. Low visual aid and suitably tinted glasses are advised.

iii. In acquired colour defects—Treatment of acquired colour defect is essentially treatment of the causative disorder. However, one should remember that often the cause is iatrogenic, i.e. side effect of drugs.

CHAPTER

6 The Neurology of Vision

VISUAL PATHWAY

The visual pathway can be described in the following order (Fig. 6-1);

I. End organ (or sensory receptor)–Rods and cones, with their nuclei and processes, of the retina constitute the end organ, i.e. sensory receptor of vision (Fig. 6-1).

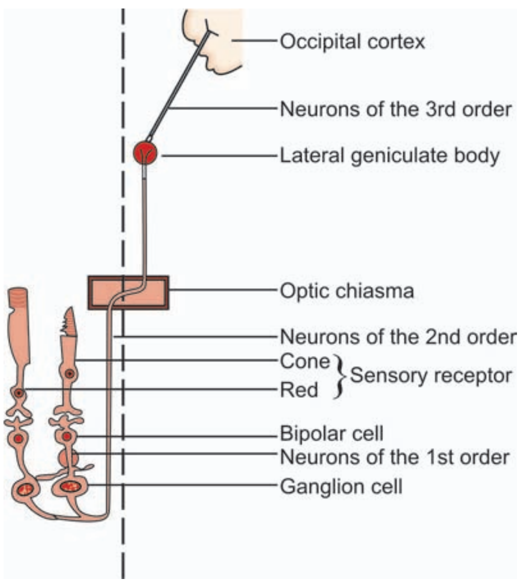


Fig. 6-1: Visual pathway

II. Cells and neurons of the 1st order—Bipolar cells present in the inner nuclear layer of the retina represent the cells of the 1st order and it's axons in the inner plexiform layer represent the neurons of the 1st order (Fig. 6-1).

III. Cells and Neurons of the 2nd order—Ganglion cells present in the ganglion cell layer of the retina constitute the cells of the 2nd order. It's processes which pass into the nerve fibre layer and along the optic nerve to the lateral geniculate body represent the neurons of the 2nd order (Fig. 6-1).

IV. Cells and neurons of the 3rd order—A new cell at the lateral geniculate body constitutes the cell of the 3rd order of neuron. Their neurons carry the visual impulse through the optic radiations to the occipital cortex, i.e. the visual centre (Fig. 6-1).

Thus, the visual pathway anatomically consists of the optic nerves, the optic chiasma, the optic tracts, the lateral geniculate bodies, the optic radiations and the occipital cortex.

COURSE OF NERVE FIBRES FROM THE RETINA IN THE VISUAL PATHWAY

- Fibres from the peripheral retina enter the periphery of the optic nerve. Nerve fibres from the peripheral retina form two distinct groups, corresponding to the temporal and nasal halves of the retina (Fig. 6-2).
- Fibres near the optic disc enter the central area of the optic nerve.
- Fibres from the macular region, i.e. the papillomacular bundles enter the optic nerve on it's outer aspect and soon become centrally positioned in the posterior part of the nerve.
- Temporal fibres enter the optic tract of the same side while the nasal fibers decussate at the optic chiasma and cross into the optic tract of the opposite side to reach the lateral geniculate body (Fig. 6-2).
- The 3rd order of neurons originating from the lateral geniculate body pass by the central area of the optic radiations and terminate at the occipital cortex of the same side (Fig. 6-2).

Hence, it is obvious that a lesion of the occipital lobe, the optic radiation or the optic tract will result in blindness of the temporal half of the retina of the same side and nasal half of the retina on the opposite side. Therefore, such a lesion will cause hemianopia which represents loss of vision in the opposite half of binocular field of vision.

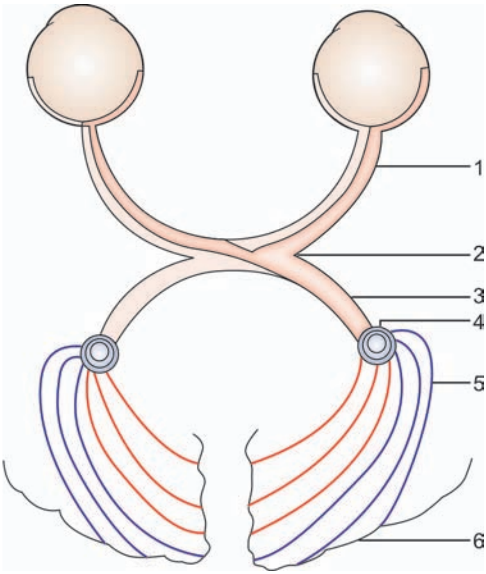


Fig. 6-2: Course and distribution of the nerve fibres in the visual pathway. **1** = Optic nerve, **2** = Optic chiasma, **3** = Optic tract, **4** = Lateral geniculate body, **5** = Optic radiation and **6** = Occipital cortex

PUPILLARY PATHWAY

The size of the pupil is controlled by the opposing forces of two involuntary muscles present in the iris; the sphincter pupillae and the dilator pupillae. The sphincter pupillae muscle is innervated by the parasympathetic system through the 3rd cranial nerve (Fig. 6-3). Parasympathetic fibres from the Edinger-Westphal nucleus enter the main trunk of the oculomotor nerve and run upto the orbit. Here, the fibres pass into the branch supplying the inferior oblique muscle. Soon they enter the short root of the ciliary ganglion to reach the ciliary ganglion. Then, they pass through the short ciliary nerve to pierce the sclera near the optic nerve and pass forward through the choroid and the ciliary body into the iris (Fig. 6-3).

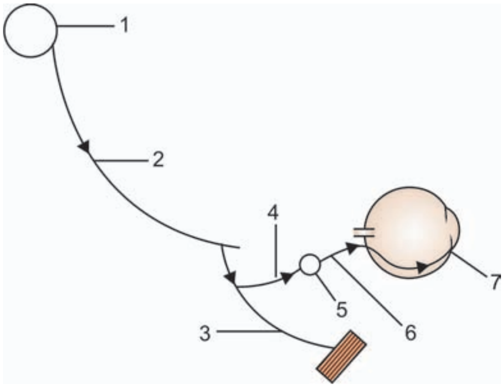


Fig. 6-3: Innervation of the sphincter pupillae muscle. **1** = Edinger-Westphal nucleus, **2** = 3rd cranial nerve trunk, **3** = Branch to inferior oblique muscle, **4** = Short root of ciliary ganglion , **5** = Ciliary ganglion, **6** = Short ciliary nerve and **7** = Sphincter pupillae

The dilator pupillae muscle is innervated by the sympathetic system through a three-neuron chain. The neuron of the 1st order of the sympathetic fiber commence from the hypothalamus which is adjacent to the Edinger-Westphal nucleus. The axon extends through the brainstem, down the spinal cord to synapse at the ciliospinal centre of Budge at the level of lower cervical and upper thoracic spinal cord (C_8–T_2). The neuron of the 2nd order passes through paravertebral sympathetic chain to the superior cervical ganglion at the level of angle of the jaws. The neuron of the 3rd order arises from the superior cervical ganglion. The sympathetic pupillary fibres reenter the skull with the internal carotid artery. The fibres pass into the ophthalmic division of the trigeminal (5th cranial) nerve from where they enter the nasociliary branch. The fibers now pass into a branch of the nasociliary nerve, the long ciliary nerves. The long ciliary nerves enter the sclera on either side of the optic nerve (accompanied by the long ciliary arteries) and pass forward between the sclera and the choroid to reach the iris via the ciliary body (Fig. 6-4). The neurons of the 1st and 2nd order are jointly referred to as preganglionic, whereas the neuron of the 3rd order is referred to as postganglionic.

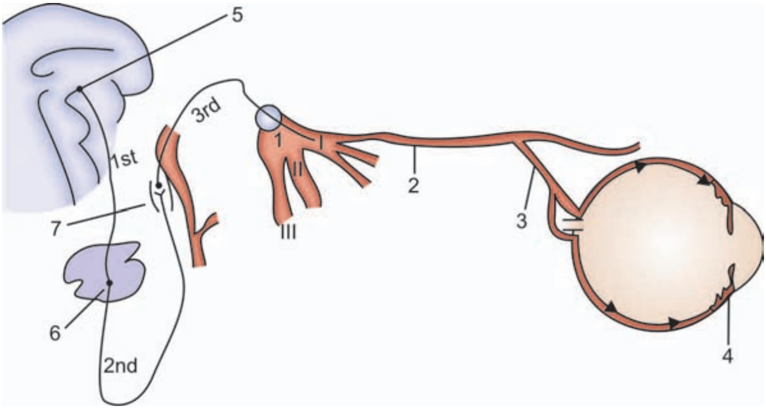


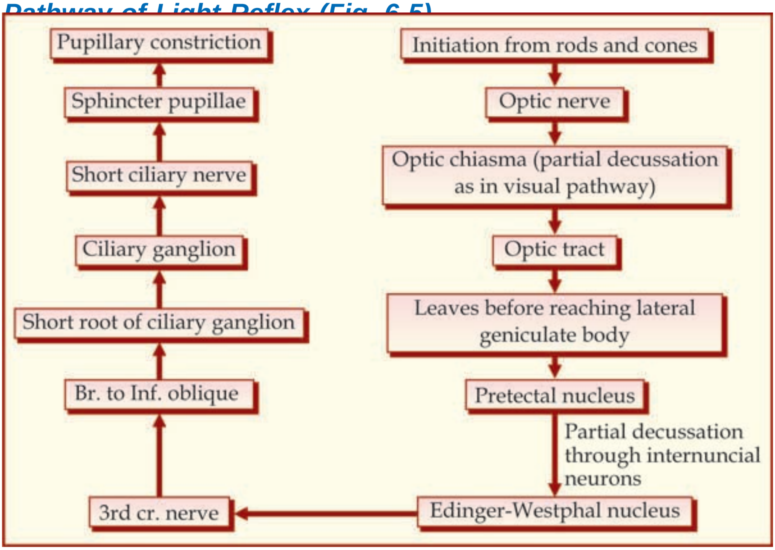
Fig. 6-4: Innervation of the dilator pupillae muscle. **1** = Trigeminal nerve, (**I** = Ophthalmic division, **II** = Maxillary division, **III** = Mandibular division), **2** = Nasociliary nerve, **3** = Long ciliary nerve and **4** = Dilator pupillae, **5** = Hypothalamus, **6** = Ciliospinal centre of Budge and **7** = Superior cervical ganglion

PUPILLARY REFLEXES

LIGHT REFLEX

If light is focused into an eye, the pupil of that eye constricts (direct light reflex) and the pupil of the other eye shows equal constriction (consensual or indirect light reflex).

Pathway of Light Reflex (Fig. 6-5)



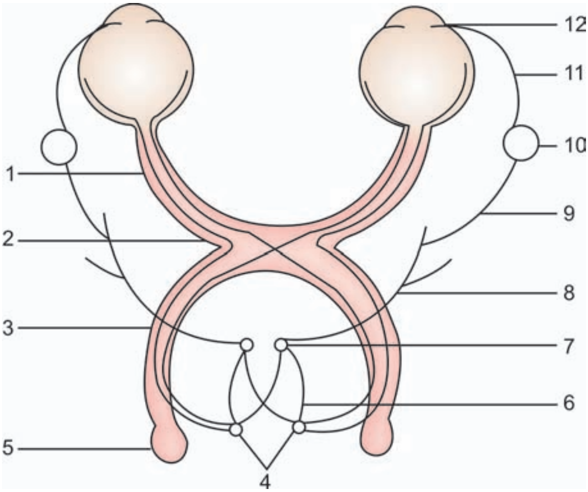


Fig. 6-5: Pupillary light reflex (retino-tectal) pathway. **1** = Optic nerve, **2** = Optic chiasma, **3** = Optic tract, **4** = Pretectal nucleus, **5** = Lateral geniculate body, **6** = Internuncial neurons, **7** = Edinger-Westphal nucleus, **8** = 3rd Cr. nerve, **9** = Short root of ciliary ganglion, **10** = Ciliary ganglion, **11** = Short ciliary nerve and **12** = Sphincter pupillae

The decussation well explains the mechanism of consensual light reflex and effect of lesion in the following sites (Fig. 6-5):

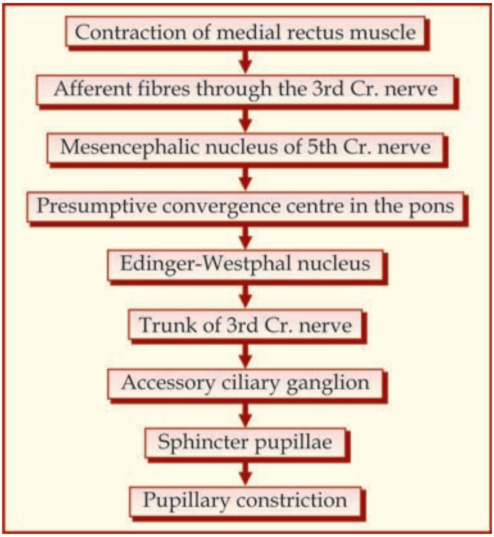
- Lesion distal to the optic chiasma—Absence of direct light reflex on the same side and consensual light reflex on the other side. Presence of direct light reflex on the other side and consensual light reflex on the same side (unilateral amaurotic paralysis).
- Lesion in the optic tract before the pupillary fibres leave the optic tract—Contralateral hemianopic reaction/paralysis/ Wernicke reaction.
- Lesion in the optic tract after the pupillary fibres leave the optic tract and in the visual pathway proximal to it—Normal pupillary reactions.

NEAR REFLEX

It is the constriction (or miosis) of the pupil on convergence. It is initiated by contraction of the fibres of the medial rectus muscle on convergence. It consists of three complex components;

convergence, increased curvature of the crystalline lens and pupillary constriction.

Pathway of Near Reflex



Sensory Reflex

It is a more complicated reflex process since both the dilator centre and the constrictor centre is involved in it's pathway. Sensory stimulation initially causes a rapid dilatation of the pupil (mydriasis) due to enhanced dilator tone through the cervical sympathetic nerve. It is followed by another dilatation, rapid in onset but slow in disappearance, due to inhibition of the constrictor tone.

PUPILLARY REACTION DISORDERS

HIPPUS

- It is seen in multiple sclerosis.
- It is characterised by alternate large rhythmic pupillary dilatation and constriction. It is often independent of the light stimulation.

MARCUS GUNN PUPIL (OR RELATIVE AFFERENT PUPILLARY DEFECT—RAPD)

- It is seen in unilateral optic neuritis, retrobulbar neuritis or multiple sclerosis.
- It is due to lesion in one of the optic nerves (Fig. 6-5).
- It is a pupillary reflex disorder characterised by *smaller constriction of both the pupils when light is focused on the affected eye*.
- It is diagnosed by **swinging flash light test**. The test is done in a darkened room with the patient fixating at a distant target. On swinging a light from one eye to the other, stimulation of the normal eye will show constriction of both the pupils. However, rapid stimulation of the affected eye will lead to a small dilatation which is also known as *pupillary escape*.

ADIE'S PUPIL (OR TONIC PUPIL)

- It is usually an unilateral (in 80% of cases) dilated but tonic pupil (anisocoria).
- It is called "Adie's pupil", if the cause is not identified. However, it is termed as "Tonic pupil" if the aetiology is detected.
- Etiology includes; viral infection of the ciliary ganglion or the short ciliary nerve (Fig. 6-5), injury to the ciliary ganglion or the short ciliary nerve, giant cell arteritis, syphilis, diabetes mellitus, herpes zoster, orbital infection, etc.
- Bilateral Adie's pupil is often seen in association with syphilis and sarcoidosis.
- Very poor pupillary light reflex response (both direct and consensual).
- Delayed and slow near reflex response.
- It typically affects adult women.
- It is associated with absent tendon reflexes.
- Very dilute pilocarpine eyedrop (0.1%) will constrict an Adie's pupil, whereas a normal pupil will not constrict.

ARGYLL–ROBERTSON PUPIL

- It is characterised by absence of pupillary reaction to light reflexes (both direct and consensual) and retention of pupillary reaction on accommodation and convergence (near reflex), i.e. pupillary light near dissociation.

- The pupils are small and usually unequal.
- Vision is unaffected.
- Aetiology–Tabes dorsalis (neurosyphilis).
- It is caused by a lesion involving internuncial neurons between the Edinger-Westphal nucleus and the pretectal nucleus (Fig. 6-5).

HORNER'S SYNDROME

- It is characterised by unilateral miosis, partial ptosis, slight elevation of the lower lid, enophthalmos and heterochromia (in congenital variety).
- It is occasionally accompanied by unilateral absence of sweating of the face (anhidrosis) and flushing of the face.
- Pupillary reactions to light and near reflexes are normal.
- Aetiology–Usually, it results from damage of the cervical sympathetic nerve in apical bronchial carcinoma.
- 10% cocaine eyedrop dilates a normal pupil, whereas pupil in Horner's syndrome will not dilate.
- Hydroxyamphetamine eyedrop (1%) is clinically used to distinguish between 3rd order neuron defect and, 1st and 2nd order neuron defect.
- 3rd order neuron lesion is indicated by failure of the pupil with Horner's syndrome to dilate to an equal degree as the fellow eye.

The diameter of the pupil can be measured using Haab's pupillometer. It contains a series of graduated circles for comparison with the pupillary diameter.

Section 3

Light and Optical Principles

CHAPTER 7

Light and Human Eye: Basic Optical Principles

LIGHT AND ELECTROMAGNETIC SPECTRUM

Light is defined as a form of energy to which the human eye is sensitive. The electromagnetic spectrum ranges from gamma rays on the short wave length end to radiowave rays on the longer wavelength end (Fig. 7-1). Optical radiation consists of ultraviolet rays, visible rays and infrared rays. However, the visible light (400 –700 nm) band is responsible for visual sensation.

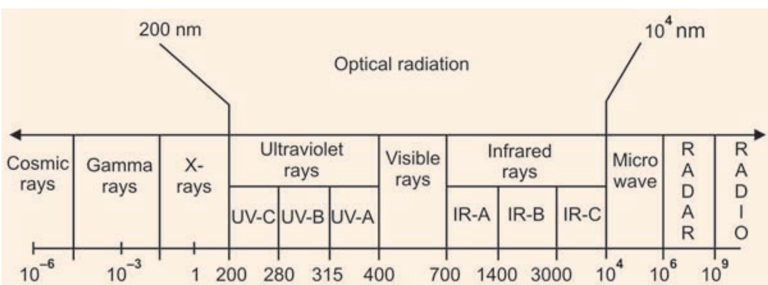


Fig. 7-1: Electromagnetic spectrum [wavelength (λ) in nm]

The energy of the individual photons of the electromagnetic spectrum is inversely related to it's wavelength. Thus, the shorter the wavelength, the greater the energy of the individual photons of optical radiation. Ultraviolet rays and infrared rays are responsible for certain radiational damage to ocular tissues.

ULTRAVIOLET RAYS (UV RAYS)

UV light is invisible and sunlight is the principal source of UV light.

UV light is further subdivided depending on their absorption spectrum into 3 bands (Figs 7-1 and 13-4);

i. UV–C (200–280 nm)— This band of UV rays from sunlight is blocked by the ozone layer (O_3) of the earth's atmosphere. However, the ozone layer is less thick at high altitudes and near the equator. Hence, the amount of absorption of UV–C rays by atmosphere varies.

ii. UV–B (280–315 nm)—This band of UV rays is blocked by the corneal epithelium. UV–B is responsible for snow blindness from reflected sunlight and corneal burn (photokeratitis) from arc welding. Cornea is also susceptible to prolonged UV–B radiation resulting in pinguecula and pterygium.

iii. UV–A (315–400 nm)—Retinal photoreceptors are sensitive to UV rays between 350–400 nm. However, this band of UV rays (UV–A) is absorbed by the crystalline lens (315–380 nm). Hence, the retina is protected against UV rays radiation. Prolonged exposure to low dose of this radiation can cause cataract. So, in aphakia and pseudoaphakia eyes (IOL without UV filter) experience a sensation of blue or violet colours. Thus, intraocular lens implants are suitably impregnated with UV–A inhibitor called "chromophores" to protect the retina.

VISIBLE RAYS

It is actually composed of seven colours of specific wavelengths. The red colour is on the longer wavelength side and violet is on the shorter wavelength end. In photopic conditions (bright light) the retina is maximally sensitive to 555 nm (yellow–green) wavelength, whereas in scotopic conditions (dim light) it is sensitive to 510 nm (blue) wavelength.

INFRARED RAYS

Infrared rays are also invisible and are further subdivided into three bands, depending on their absorption spectrum (Fig. 7-1);

1. IR–A (700–1400 nm)—Excess exposure to these IR rays may cause eclipse blindness and cataract.

2. IR–B (1400–3000 nm)—Excess exposure to these IR rays may cause corneal opacity and cataract.
3. IR–C (3000–10^4 nm)—Excess exposure to these IR rays may cause corneal opacity and cataract.

Most of the infrared rays (Fig. 7-1) are absorbed in the anterior chamber of the eyes and cause a rise in temperature. Hence, they are also called heat rays. Cornea and sclera absorbs infrared rays of wavelength beyond 1400 nm (IR–B and IR–C). Hence visible rays (400–700 nm) and infrared rays of wavelengths between 700–1400 nm (IR–A) are partly transmitted to the retina (see Fig. 13-4 in chapter-13). Infrared rays absorption during solar eclipse cause photoretinitis, i.e. eclipse blindness.

BASIC OPTICAL PRINCIPLES OF HUMAN EYE

Optics of the human eye consist of fluid optical mediums and solid optical mediums. Aqueous humour and vitreous humour constitute the fluid mediums, whereas cornea and the crystalline lens form the solid mediums. However, practically refraction by the eye takes place at the anterior corneal surface and the two surfaces of the crystalline lens due to the following reasons:

- Refractive indices of the corneal stroma and aqueous humour are considered equal for practical purpose.
- Refractive indices of aqueous humour and vitreous humour are same.
- Anterior corneal surface contributes to major part of refraction of the eye due largely to significant difference in refractive indices of cornea (RI = 1.376) and air (RI = 1) and convexity of the central part of the cornea.
- Posterior corneal surface is concave with shorter radius of curvature and is in contact with the aqueous humour. This weakens the negative power attributed by the posterior corneal surface. So, cornea forms the major optical element of the eye with an average dioptrical strength of +42.5D (+40 to +45D).
- The crystalline biconvex lens has an average dioptrical strength of +18D (+16 to +20D). The refractive index of the lens varies due to lack of optical homogenecity. The refractive index

gradually decreases from the inner core of the nucleus to the outer cortex in a gradient manner. However, the optical power of the lens is not stationary and can be increased to see near objects by the process known as accommodation.

Image of an object is refracted by the converging strength of the eye to the surface of the retina which initiates the process of visual sensation. Additionally, better quality of retinal images are formed due to the aspherical refracting surfaces of the eye. This aspheric quality is rendered by the flatter peripheral surfaces of the refracting surfaces then the central area.

SCHEMATIC EYES

Schematic eyes are designed to simplify optics of the eyes to replace the complex optics of the human eye. Schematic eyes assumes:

- The eye is homocentric, i.e. presence of a common optical axis.
- The refracting surfaces are spherical.
- The cornea and the lens form the optical refracting elements.

Different types of schematic eyes are designed taking into account various parameters from a simple one to a complex one.

Gullstrand Schematic Eye No. 1

- Gullstrand's schematic eye provides us with the numerical values for the radii of curvature, indices of refraction, distance between the refracting surfaces and location of the principal points, nodal points and focal points (Fig. 7-2).
- Gullstrand's schematic eye no. 1 has six refracting surfaces and this eye has a refractive error of +1D possibly to neutralise the relative myopia produced by spherical aberrations through peripheral areas of pupil.
- The accommodation exerted in accommodative state is 10.6D.
- Gullstrand described schematic eye in both unaccommodated and maximally accommodated state, with a change in variables involving the lens only.
- In this eye, power of the cornea is +43.00D and power of the lens is +19.11D.

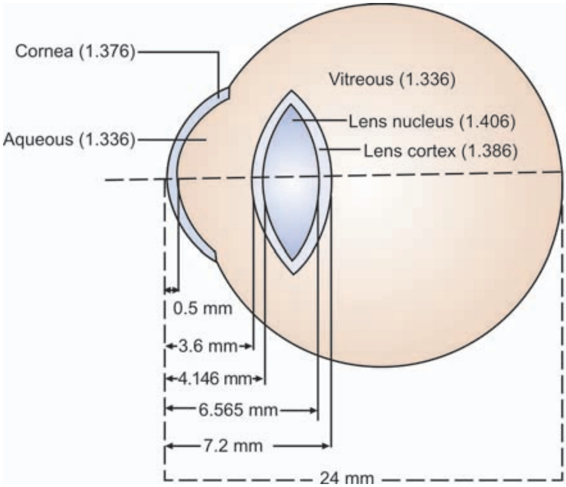


Fig. 7-2: Gullstrand's schematic eye no. 1 showing numerical values of various parameters

Gullstrand–Emsley Schematic Eye

Emsley developed this schematic eye with the following modifications (Fig. 7-3) of the Gullstrand's schematic eye no. 1:

- The lens is made optically homogeneous, i.e. the central nuclear area having different refractive index is abolished.

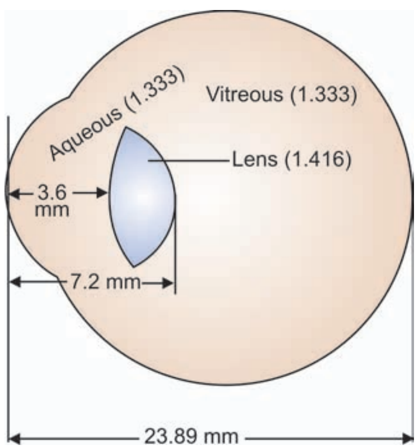


Fig. 7-3: Gullstrand–Emsley schematic eye

- The posterior corneal surface is also removed.
- So, no. of refracting surfaces is reduced to 3 from earlier 6 surfaces.
- The refractive index of aqueous humour and vitreous houmour is changed from 1.336 to 1.333.
- The Gullstrand–Emsley schematic eye is emmetropic, as opposed to the Gullstrand schematic eye no. 1 which is +1.00D hypermetropic.

Donder's Reduced Eye

"Reduced Eye" is constructed by Donder with the following modifications (Fig. 7-4) of the schematic eyes.

- It has only one refracting surface, i.e. the cornea with the elimination of the lens.
- It's total dioptric strength is +58.6D and refractive index is 1.336.
- It is emmetropic with the second focal length, i.e. axial length of 24.13 mm. The second focal point is on the retina. The first focal point is –15.7 mm in front of the cornea.
- Radius of curvature of the cornea is 5.73 mm, as opposed to 7.7 mm in a schematic eye.
- Since there is only one refracting surface, the first and second principal planes, points and nodal points merge to form only one principal plane, principal point and nodal point (Fig. 7-4).

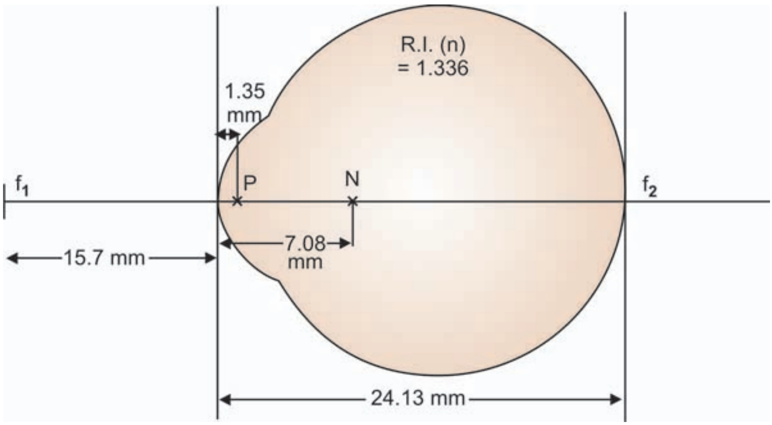


Fig. 7-4: Donder's reduced eye. P = Principal point; N = Nodal point; f_1 = First focal point; f_2 = Second focal point

- The principal point is 1.35 mm behind the anterior corneal surface and the nodal point is 7.08 mm behind the anterior corneal surface (Fig. 7-4).

Emsley also constructed "reduced eye" with the numerical values of various parameters as follow:

- Refractive index = 1.333
- Dioptric strength = +60.00D
- First focal point (f_1) = – 16.67 mm in front of the cornea
- Second focal point (f_2) = + 22.22 mm behind the cornea
- Axial length of this reduced eye = +22.22 mm
- Radius of curvature of cornea = 5.55 mm.

Clinical Application of Reduced Eye

- Calculation of retinal image size
- Designing of ophthalmic instruments
- Calculation of intraocular lens (IOL) power.

AXES AND ANGLES OF THE EYE

The pupil is slightly decentred, the lens is tilted and the fovea is not aligned with the optic axis. Hence, the eyeball is not a perfectly centred one, the radius of curvatures of different refractive surfaces of the eye do not fall on a common optic axis.

AXES

Optic Axis

It is the straight line which passes through centres of curvatures of different media of the eye, as close as possible (Fig. 7-5).

Pupillary Axis

It is the straight line which passes through the centre of the pupil.

Visual Axis

It is the straight line which passes through the fovea and the nodal point (Fig. 7-5) of the eye.

Fixation Axis

It is the line joining the fixation point with the centre of rotation of the eyeball (Fig. 7-5).

ANGLES

Angle Alpha (α)

It is the angle formed between the optic axis and the visual axis (Fig. 7-5).

Angle Kappa (κ)

It is the angle formed between the pupillary axis and the visual axis (Fig. 7-5).

Angle Gamma (γ)

It is the angle formed between the optic axis and the fixation axis (Fig. 7-5).

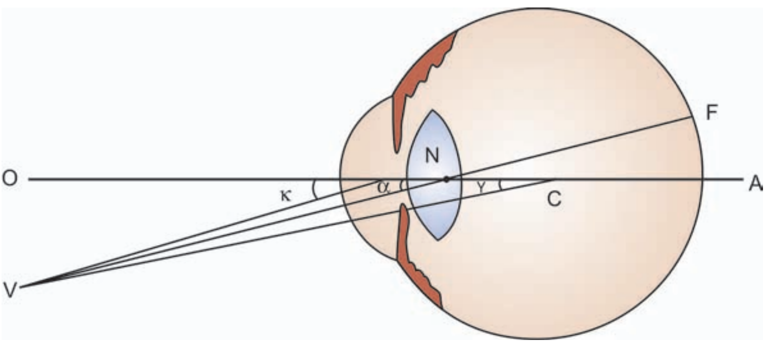


Fig. 7-5: Axes and angles of the eye. OA = Optic axis; α = Angle alpha; VF = Visual axis; κ = Angle kappa; VC = Fixation axis; γ = Angle gamma and N = Nodal point

These angles are usually positive i.e., the visual axis is nasal to the optic axis. They approximately measure 5°.

OPTICAL ABERRATIONS OF THE EYE

Since the eyeball is not optically perfect, it shows some optical flaws which reduce resolution of the focussed images. They are called "aberrations". However, several mechanisms operate at different areas of the eye to eliminate or minimise these aberrations. These are:

- Blocking of peripheral rays of light by the iris diaphragm (Fig. 7-7B).
- Gradient nature of refractive index of the lens from the central nucleus to the peripheral cortex.
- Aspherical surface of the cornea, i.e. the peripheral area is flatter and the central area is more convex.
- Stiles–Crawford effect, i.e. greater sensitivity of the retinal photoreceptors (cones only) to paraxial rays than the rays which enter obliquely through the peripheral cornea. Stiles-Crawford effect occurs only in photopic vision.
- Curved surface of the retina eliminates curvature of field, a type of monochromatic aberration.

Aberrations may be classified as (Fig. 7-6);

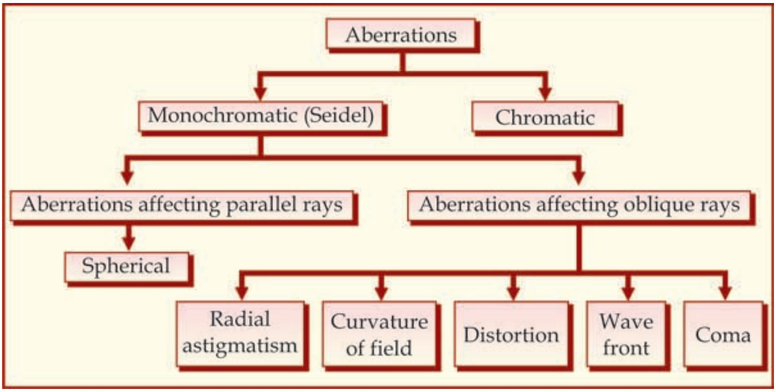
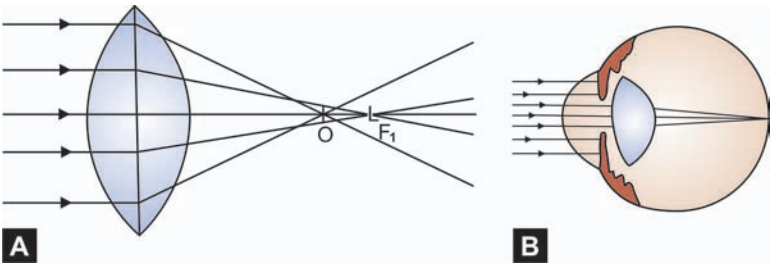


Fig. 7-6: Classification of optical aberrations

SPHERICAL ABERRATIONS

In a convex spherical lens the refractive power of the peripheral areas are more than the central areas. So, in a convex lens central parallel rays are brought to a single point focus (F_1). However, peripheral rays come to a focus (O) nearer to the lens then the point focus F_1. This results in a blurring of images particularly at the edges (Fig. 7-7A). It is termed positive spherical aberration. However, in a concave spherical lens the peripheral rays come to a focus after the central ones and it is termed negative spherical aberration. Spherical aberration is classified under monochromatic Seidel aberration and is the only type which effects parallel rays of light, i.e. on–axis objects. So, large, i.e. dilated pupil contributes to spherical aberration, i.e. visual blur. Spherical aberration can be neutralised or minimised by either using a lens in which refractive index varies in a gradient manner or an aplanatic lens.



Figs 7-7A and B: (A) Spherical aberration (B) Spherical aberration blocked by iris diaphragm

COMA

It is a type of monochromatic aberration that effects only off-axis objects, i.e. oblique rays. Rays passing through the periphery of the lens are more refracted than the central rays and come to a focus nearer the principal axis than the central rays. This results in unequal magnification of images formed by the rays passing through different areas of the lens. This gives rise to a composite elongated image simulating a comet or coma (Fig. 7-8). If the head of the comet point towards the optical axis, it is called positive coma while if it points away from the optical axis it is called negative coma. Aplanatic lens can correct both spherical aberration and coma. Also a combination of lenses with positive and negative coma can cancel each other.

OBLIQUE/RADIAL ASTIGMATISM

Axial astigmatism occurs with toric lens, whereas spherical, i.e. nontoric lenses exhibit oblique astigmatism with only oblique rays, i.e. off-axis objects. It occurs due to the fact that spherical lenses

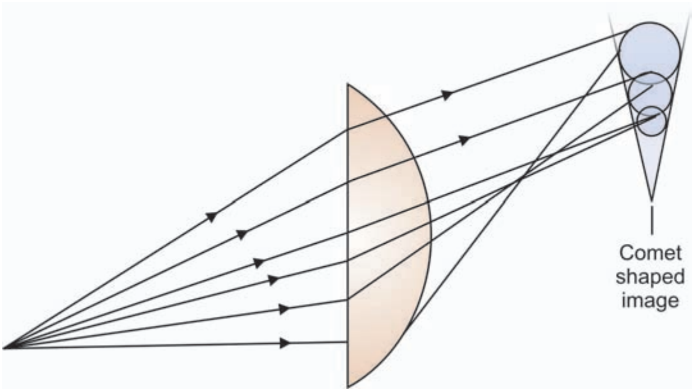


Fig. 7-8: Coma produced by rays passing obliquely through a lens

show different refractive powers in different meridians only when oblique rays fall upon them.

DISTORTION

Image distortion occurs due to increased prismatic effect of the periphery of the lens resulting in difference in lateral magnification at different points on an object. A classical example of distortion is a grid object distorted as either barrel or pincushion observed in concave lens and convex lens respectively (Fig. 7-9). Image distortion persists even after elimination of all other Seidel aberrations.

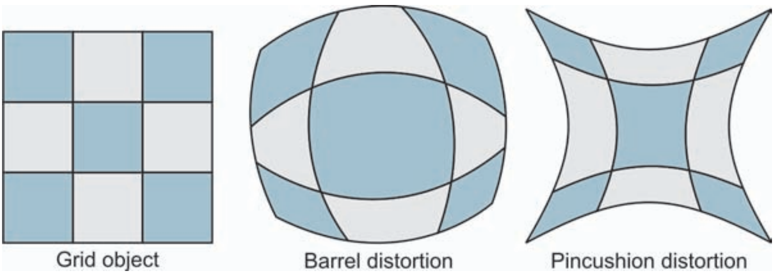


Fig. 7-9: Different types of distortion

CURVATURE OF FIELD

Curvature of field is closely related to oblique/radial astigmatism and means that a plane object gives rise to a curved image. After optical elimination of spherical aberration, coma and radial astigmatism irrespective of parallel/oblique rays a point object will form a point image. These points will be seen to fall on a curved surface (Petzval surface) which phenomenon is called curvature of field (Fig. 7-10). Due to this curvature of field if an extended image is projected on a flat surface some of the points will not be in focus.

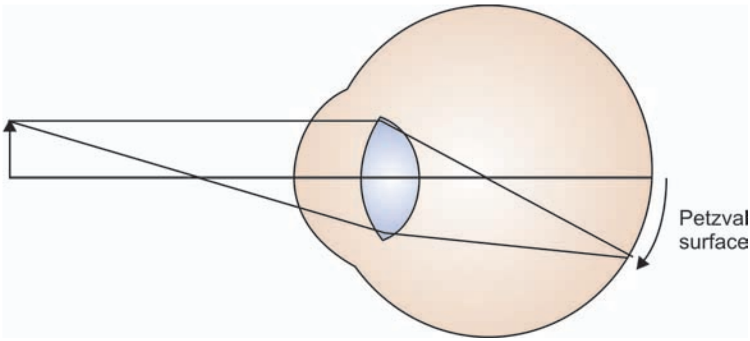


Fig. 7-10: Curvature of field

WAVEFRONT ABERRATION

Wavefront aberration is defined as the amount of difference between an ideal wavefront and the actual wavefront emanating from an optical system. This wavefront aberration is measured by the method "aberrometry". Clinical applications of aberrometry include:

- Corneal refractive surgery
- Intraocular lenses, etc.

CHROMATIC ABERRATION

White light consists of seven colours. The component colours are refracted differently at spherical surfaces and the image formed have a coloured edge, which is recognised as chromatic aberration. The short wavelength blue rays are refracted the most and come to a focus in front of the retina, i.e. the eye is myopic for blue rays

(Fig. 7-11). Similarly, the red rays with longer wavelength are refracted the least and come to a focus behind the retina, i.e. the eye is hypermetropic for red rays (Fig. 7-11). The yellow light rays with medium wavelength will come to a focus in the retina, i.e. the eye is emmetropic for yellow rays (Fig. 7-11). However, in human eye visual acuity is surprisingly good although there should be considerable blurring due to uncorrected chromatic aberration. The reasons are:

- The xanthophyll pigments present in the macular area filter out the blue rays, the most offender in chromatic aberrations.
- Since luminous efficiency of the eye is brightest for the yellow rays (in the middle of the visible light spectrum) blue and red coloured rays appear significantly less bright to cause visual blur noticeably.
- Additionally, the lens even in younger subjects filters out UV-A rays.
- Blue rays are filtered out by the lens which turns yellow in nuclear sclerosis with advancing age.

Chromatic aberration is clinically applied in duochrome test (subjective refraction test). Chromatic aberration is corrected by using "achromatic lens". This is made by combining a convex lens of crown glass of refractive index 1.523 with a concave lens of flint glass (RI = 1.7) of half dioptrical strength. The principle is to neutralise the chromatic aberration by combining the lenses that induce opposite chromatic aberrations.

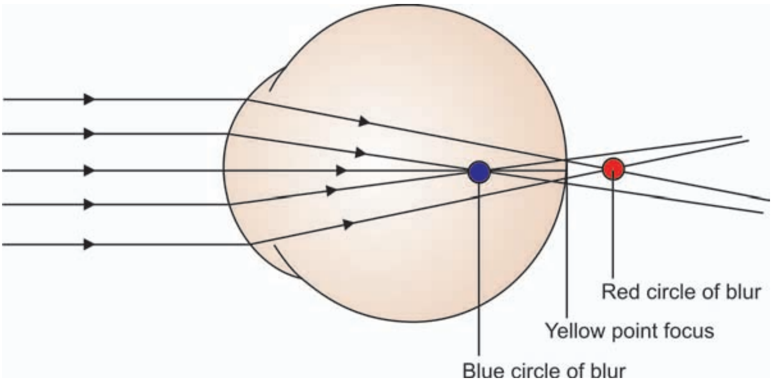


Fig. 7-11: Chromatic aberration

PURKINJE IMAGES

These are four in number (Table 7-1) and they are the images of a light reflected from the different refracting surfaces of the eye, described first by JE Purkinje, a Czech scientist.

Table 7-1: Features of Purkinje images

1st Purkinje Image	It is formed by reflection from the anterior corneal surface. It is a virtual, erect image. It is brightest. Situated near pupillary plane.
2nd Purkinje Image	It is formed by reflection from the posterior corneal surface. It is a virtual, erect image. Situated near pupillary plane.
3rd Purkinje Image	It is formed by reflection from the anterior lens surface. It is a virtual, erect image. It is largest but dim. Situated in the vitreous
4th Purkinje Image	It is formed by reflection from the posterior lens surface. It is real, inverted image. It is smallest and moves in the opposite direction to other images . Situated within the lens.

Usually 1st and 2nd images are easily seen. However, in a dark room or in a dilated pupil all the images will be better visualised. If the light source is located 1 m from the eye, 1st, 2nd and 4th images are located between 3.5 to 5 mm behind the anterior corneal surface, while the 3rd image is located 11 mm (approx.) from the anterior corneal surface (Fig. 7-12).

CLINICAL APPLICATION OF PURKINJE IMAGES:

- Presence or absence of lens
- Types of cataract
- Keratometry
- Hirschberg test—estimation of angle of squint.

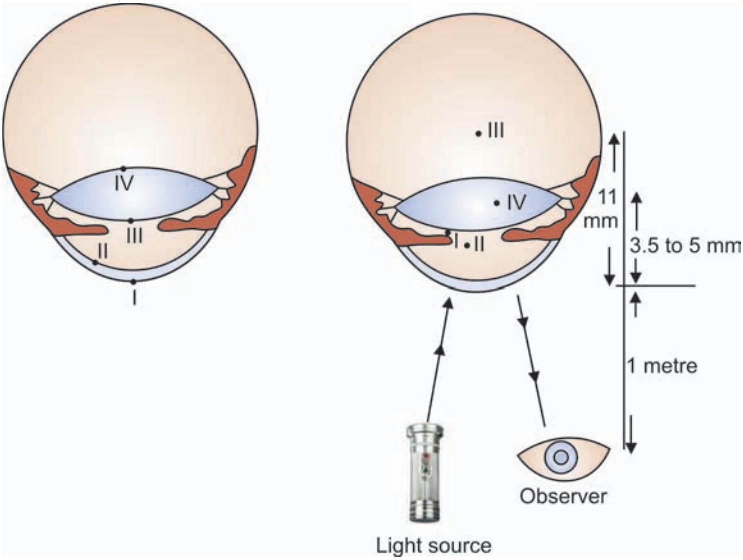


Fig. 7-12: Source and location of Purkinje images.
(light source is 1m from the eye)

RETINAL IMAGE

In a reduced eye, the rays passing through the nodal point (N) are not refracted and passes straight to the retina (Fig. 7-13). The retinal image (ab) is formed of the object AB.

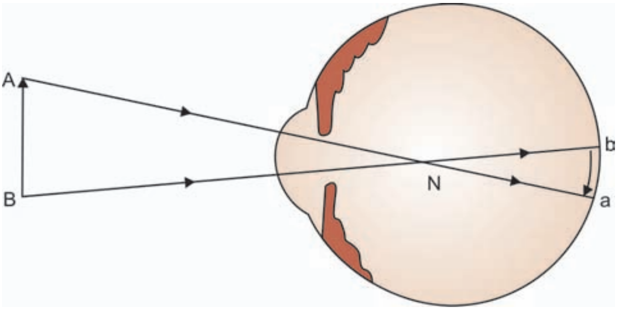


Fig. 7-13: Retinal image formation.
AB = Object, ab = Image and N = Nodal point of the eye

The retinal image thus formed is inverted and minified. This image is psychologically again inverted at the cerebral cortex. The true size of the image is also estimated at the cerebral cortex.

CHAPTER

8 Accommodation and its Anomalies

ACCOMMODATION

Accommodation is defined as the phenomenon/process to focus near objects clearly on the retina by increasing the convergence power of the eye. This is achieved by increasing the refractivity of the crystalline lens through increasing the curvature of it's anterior surface mainly. At rest, i.e. in unaccommodated state, the radius of curvature of the anterior surface is 10 mm and that of the posterior surface is 6 mm. In accommodation, the radius of curvature of the posterior surface remains almost unchanged. But in strong accommodation the radius of the curvature of the anterior surface becomes 6 mm, i.e. more convex and takes on a more hyperboloid form.

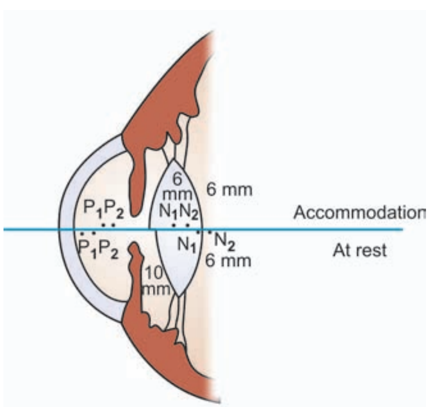
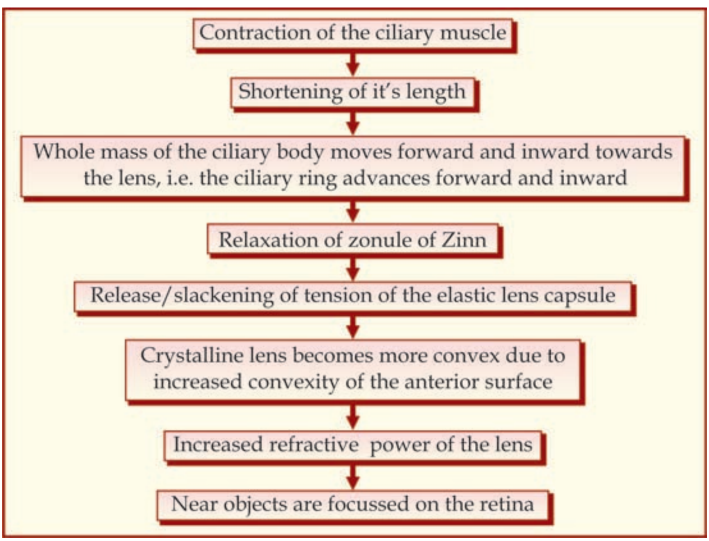


Fig. 8-1: Anatomical changes in the eyeball in cross section during accommodation (upper half) and at rest (lower half), N_1 = Front nodal points, N_2 = Back nodal points, P_1 = Front principal points and P_2 = Back principal points

The dioptric power of the eye in this accommodative state is called it's dynamic refraction. The dioptric power of the resting eye is called it's static refraction. Anatomical changes associated with accommodation are (Fig. 8-1):

- Decreased radius of curvature of anterior surface of the lens from 10 mm to 6 mm.
- Increased thickness of the lens by 0.50 mm.
- Decreased equatorial diameter of the lens from 10 mm to 9.6 mm.
- Anterior axial displacement of the anterior pole of the lens by 0.30 mm and consequent decreased depth of anterior chamber also by 0.30 mm.
- During accommodation, all the cardinal points of the eye move toward the anterior surface of the lens (Fig. 8-1).

MECHANISM OF ACCOMMODATION



Understanding of mechanism of accommodation is based on Von Helmholtz theory (1909). The shape of the lens is basically a balance between the elastic forces of the lens capsule and viscoelasticity of the lens mass.

1. *Far point (Punctum Remotum):* It is the furthest point at which objects can be focussed on the retina, when the ciliary muscle is relaxed, i.e. accommodation is at rest. The far point which is conjugate to the retina (Fig. 8-2) varies according to it's static refraction (emmetropia, myopia or hypermetropia).
2. *Near point (Punctum Proximum):* It is the closest point at which small objects can be focussed on the retina clearly after maximum accommodation and the near point is conjugate to the retina (Fig. 8-2).
3. *Range of accommodation:* It is the distance between the far and near points, e.g. from infinity to 20 cm.
4. *Amplitude of accommodation:* It is the difference in refractive power of the eye between near point and far point. Amplitude of accommodation gradually declines to become zero at the 6th decade.

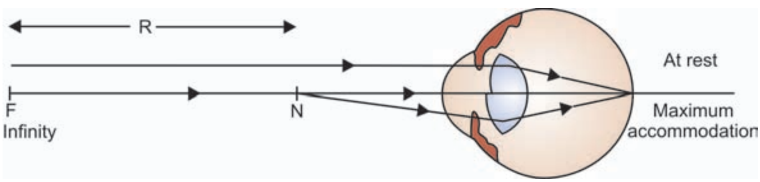


Fig.8-2: Far point and near point in an emmetropic eye.
F = Far point, N = Near point and R = Range of accommodation

Following two other phenomena occur along with accommodation:

- Pupillary miosis–It increases depth of focus and reduces aberrations.
- Convergence, i.e. inward rotation of the eyes.

A stimulus to either accommodation or convergence can cause both the change since they are controlled by the same neurological pathway.

Q. Calculate the amplitude of accommodation and range of accommodation of an eye with far point at 1 metre and a near point of 10 cm.

A. Refractive power of the eye at far point is
1/1 = 1 diopter

Refractive power of the eye at near point is
1/0.10 = 10 diopter
So, the amplitude of accommodation is = 10D–1D = 9 diopter.
The range of accommodation is = 1 m–10 cm = 100 cm–10 cm = 90 cm

INSUFFICIENCY OF ACCOMMODATION

It is a situation where the accommodative power of a person is persistently lower than appropriate level expected for the person's age. It is the most common form of accommodative disorder.

AETIOLOGY

- Early onset of presbyopia.
- Fatigue of ciliary muscle due to general weakness, influenza, poor health, anaemia, debilitating illness, etc.
- Impaired effectiveness of ciliary muscle due to increased IOP in primary open angle glaucoma (POAG).
- Working in dim/poor light for long hours.

COMPLAINTS

- Blurred vision
- Difficulty in maintaining good vision at near
- Frontal headache.

TREATMENT

- Treatment of the causal factor or illness.
- Near correction—Weakest convex lens which allows near vision at normal reading distance. Full correction is avoided to encourage exercise and stimulation of the available accommodation.
- Encourage near work at good illumination.

PARALYSIS OF ACCOMMODATION

Bilateral paralysis of accommodation is less common than paresis (partial paralysis/weakness).

AETIOLOGY

Aetiology of paralysis of accommodation can be classified as follows (Table 8-1).

Table 8-1: Aetiology of paralysis of accommodation

Unilateral cause	*Bilateral cause*
Cycloplegic induced	Diabetes mellitus
Blunt trauma	Alcoholism
Paralysis of IIIrd cranial nerve	Encephalitis
Tear in iris sphincter	Diphtheria
Horner's syndrome	Botulism
Adie's syndrome	Syphilis
Herpes zoster	Multiple sclerosis
	Lead poisoning
	Arsenic poisoning
	Typhoid

The prognosis is good in cases due to diphtheria or drugs. However, in traumatic cases the condition is often permanent. Full mydriasis is usual in total paralysis of accommodation.

TREATMENT

i. Treatment of causative factor or illness
ii. Appropriate convex lens for adequate near work is advised.

SPASM OF ACCOMMODATION

It is defined as a situation where accommodation is found to be always higher than expected. The excess accommodation is caused by involuntary contraction of the ciliary muscle. Myopia develops due to the excess of accommodation. *Pseudomyopia* develops in this accommodative disorder.

AETIOLOGY

i. It is typically seen in young myopic patient.
ii. It is also found in young patients involved in too much of near work in insufficient illumination and bad posture.
iii. It is also observed in young patients suffering from mental anxiety.

iv. It may be induced artificially by instillation of miotics, i.e. pilocarpine eyedrops in treatment of primary open angle glaucoma (POAG) in young patients.
v. It is also observed in patients suffering from uveitis.

COMPLAINTS

i. Eye strain or Asthenopia
ii. Blurring of vision for distance due to induced myopia.

DIAGNOSIS

Atropine paralyses the tone of the ciliary muscle which is +1.00D. Retinoscopy under atropinisation (cycloplegic refraction) reveals that the value is higher in such cases.

TREATMENT

i. Removal of environmental, working condition and aetiological factors.
ii. Atropinisation, i.e. use of cycloplegic drugs for several weeks and reassurance.
iii. Psychotherapy, if indicated.
iv. Correction of refractive error.

Section 4

Refractive Errors and Correction

CHAPTER

9

Errors of Refraction

INTRODUCTION

The refractive status of an eye during minimal accommodation may be of the following types: (Fig. 9-1):

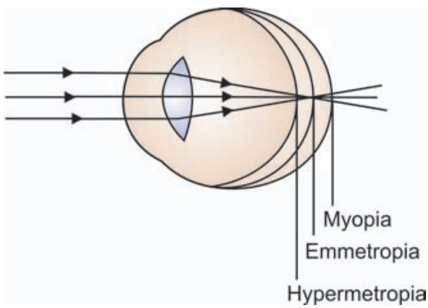


Fig. 9-1: Image formation in various states of refraction

a. *Emmetropia:* It is a condition in which parallel rays of incident light are brought to a focus upon the light sensitive layer of the retina during minimal accommodation. It indicates absence of refractive error.

b. *Ammetropia:* It indicates presence of refractive error, i.e. absence of emmetropia wherein, parallel rays of incident light are not focused on the light sensitive layer of the retina during minimal accommodation. Ammetropia may be of the following types:

   i. *Hypermetropia (or Hyperopia):* Incident parallel rays of light are brought to a focus behind the retina.

   ii. *Myopia:* Incident parallel rays of light are brought to a focus in front of the retina.

iii. *Astigmatism:* Incident parallel rays of light are brought to a line of focus instead of a single point focus due to inequality in curvature of different meridians.

Most definitions of refractive status of the eye theoretically refer to the term "when the accommodation is at rest". However, in practice it is not possible to obtain zero accommodation even in the absence of any optical stimulus to accommodation. Due to this fact, the term "minimal accommodation" is used in the definitions.

HYPERMETROPIA

It is also called long sightedness.

TYPES

Based on Anatomical Features

a. *Axial Hypermetropia*

- It is due to relatively short axial length.
- 1 mm axial length shortening will cause +3.00D of hypermetropia.
- Physiologically majority of all infants are axial hypermetropic due to small size of the globe at birth.
- Pathologically, axial hypermetropia will develop when the retina is pushed forward in ocular tumour, central serous retinopathy, etc.

b. *Curvature Hypermetropia*

- It is due to the increased radius of curvature of the refractive surfaces, i.e. cornea and lens.
- 1 mm increase in radius of curvature, i.e. flattening will cause +6.00D of hypermetropia.
- It is seen in cornea plana.

c. Index Hypermetropia

- It is due to increase in refractive index of the lens cortex relative to the nucleus, which is often seen in elderly.

d. Absence of Refractive Element

- It is due to removal of the lens, i.e. aphakia.

e. Displacement of Refractive Element

- It is due to backward displacement of lens.

Based on Accommodation

Total hypermetropia can be divided into:

a. Latent hypermetropia—Hypermetropia which is physiologically masked by accommodation, i.e. by the tone of the ciliary muscle. It is not detected by noncycloplegic refraction and is revealed only after complete cycloplegia.
b. Manifest hypermetropia—Hypermetropia which is corrected by strongest convex (plus) lens required for optimum clear distance visual acuity and is composed of:
   i. Facultative hypermetropia—It is that part of manifest hypermetropia which is masked by accommodation but can be estimated by noncycloplegic refraction.
   ii. Absolute hypermetropia—It is that part of manifest hypermetropia which cannot be corrected by accommodation.

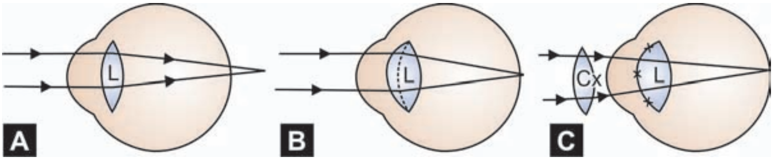
So, total hypermetropia = latent hypermetropia + manifest hypermetropia (facultative + absolute). In young children the hypermetropia represents latent hypermetropia. As age advances, the lens become less elastic and it changes towards manifest hypermetropia. So, the older the subject, the more the manifest hypermetropia.

OPTICS OF HYPERMETROPIA

In hypermetropia parallel rays of light come to a focus behind the retina (Fig. 9-2A). Hence, formation of a clear image is not possible. It may be corrected by either the effort of accommodation (Fig. 9-2B) or by placing a convex lens or contact lens in front of the eye (Fig. 9-2C). These converge the rays more and the image is being focussed on the retina (Figs 8-2B and C).

SYMPTOMS

- Eye strain, i.e. accommodative asthenopia.
- Blurred vision for near with frontal headache and occasional neckache—It occurs in older patients with early onset of presbyopia.



Figs 9-2A to C: (A) Hypermetropia (L = Lens). (B) Accommodation (Lens=L is more convex), (C) Convex Lens (C_x) in front of the eye

- Convergent squint in children.
- Latent convergent squint (esophoria) in children.
- *Pseudomyopia (or artificial myopia)*—Excessive accommodation produces a spasm of ciliary muscle resulting in an apparent myopic shift. This myopic shift will disappear under cycloplegia which relaxes accommodation by paralysis of the ciliary muscle.

SIGNS

- Shallow anterior chamber depth and a very small eyeball.
- Amblyopia is more common with high hypermetropia.
- Apparent divergent squint in children.
- Ophthalmoscopy (or Fundoscopy)–A bright reflex simulating watered silk is common. Size of the optic disc may be small. Sometimes, the small hypermetropic disc with blurred margins simulates papillitis *(pseudopapillitis)*.

RISKS INHERENT TO HYPERMETROPIA

- Amblyopia
- Primary Angle Closure Glaucoma (PACG)–It is common amongst Chinese people due to smaller size of the eyeball.
- Accommodative convergent squint.

TREATMENT

I. *Glass*

  i. Young individual with low hypermetropia and without any symptom or divergent squint or latent squint–glasses usually not required.

  ii. Older patient with hypermetropia–The strongest convex lens with which the subject maintains 6/6 (or 20/20) distant vision indicates manifest hypermetropia. The weakest convex lens which allows 6/6 (or 20/20) distant vision indicates absolute hypermetropia. So, facultative hypermetropia can be deduced by deducting absolute hypermetropia from the manifest hypermetropia. The appropriate presbyopic addition, if required, must be added to the hypermetropic correction.

iii. In children–Convex glasses are prescribed preferably after full cycloplegic refraction particularly in children with convergent squint.

II. *Contact lens*: It is particularly suitable for high degree of hypermetropia and also in aphakia.

III. *Surgical*

i. Hypermetropic LASIK
ii. Holmium: Yag laser thermokeratoplasty
iii. Phakic intraocular lens (piggy back lens) for higher degree of hypermetropia. These are foldable, thin lenses implanted between the iris and the natural lens in posterior chamber.
iv. Secondary IOL implantation in aphakic cases.

MYOPIA

It is also called short sightedness.

TYPES

Based on Anatomical Features

a. *Axial myopia*

- It is due to relatively long axial length.
- 1 mm axial length lengthening will cause –3.00D of myopia.

b. *Curvature myopia*

- It is due to decreased radius of curvature of refractive surfaces, i.e. cornea and lens.
- 1 mm steepening will cause –6.00D of myopia.
- It is found in keratoconus, lenticonus and megalocornea.

c. *Index myopia*

- It is due to increase in refractive index of the lens nucleus which occurs in nuclear sclerosis.

d. *Displacement of refractive element*
- It is due to forward displacement of lens.

Based on Clinical Types

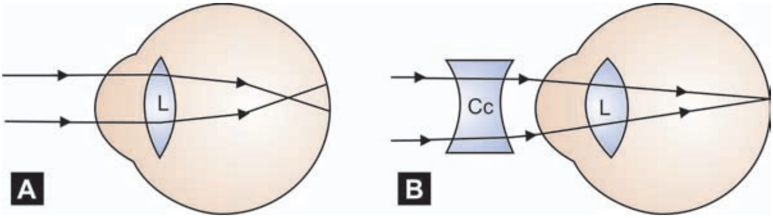
a. *Congenital (or developmental) myopia*
- Myopia present at birth with abnormally long axial length.
- Usually stationary and may be upto –10.00D at birth.
- Typical myopic fundus changes viz., prominent choroidal vessels, lack of retinal pigmentation and myopic crescent are seen.

b. *Simple myopia*
- It is the most common type.
- Develops in early years of life.
- Usually become stationary after adolescence.
- It is not accompanied by degenerative changes in the posterior pole of the retina, although peripheral retinal degenerations may be detected in later life.
- Usually upto –6.00D of error of refraction is present.

c. *Pathological (or malignant or degenerative) myopia*
- Strongly hereditary and more common in women.
- Racial factor–more common in Japanese and Jews.
- Develops in early childhood (5–10 years) and usually progresses steadily upto 30 years of age.
- The axial lengthening involves the part of the eye posterior to equator.
- It is usually found in high myopia, i.e. more than – 6.00D of myopia and the myopia may progress upto –15.00D to – 20.00D.
- It is accompanied by typical degenerative changes particularly in the posterior pole of the eye which becomes evident in later life.
- Pathological curvature myopia is ideally seen in keratoconus.

OPTICS OF MYOPIA

In myopia parallel rays of light come to a focus in front of the retina (Fig. 9-3A). Hence, a clear image is possible only by increasing the divergence of the rays, i.e. by placing a concave lens or contact lens in front of the eye (Fig. 9-3B).



Figs 9-3A and B: (A) Myopia (L = Lens), (B) Concave Lens (C_c) in front of myopic eye

SYMPTOMS

- Diminished distant vision
- Eye strain or asthenopia
- Exophoria or Latent divergent squint–It results from disproportion between accommodation effort (less in myopia) and convergence effort (lesser in myopia)
- Floaters and/or flashes of light in front of the eyes
- Photophobia and/or impaired vision at night.

SIGNS

- Prominent eyes
- Large pupil and deep anterior chamber
- Apparent convergent squint
- Vitreous degeneration leading to floaters composed of vitreous framework elements
- Ophthalmoscopy (or Fundoscopy)–Reveals the following combination of signs.

Large optic disc with large physiological cup, temporal crescent, chorioretinal degeneration imparting Tesselated appearance, dull foveal reflex, macular degeneration, posterior staphyloma, etc. Peripheral retinal degenerations are visible only with indirect ophthalmoscopy (i.e. Lattice degeneration, pigment clumps, etc).

RISKS INHERENT TO MYOPIA

- Peripheral retinal degenerations are more common which may lead to retinal tear and retinal detachment.
- Vitreous degenerations and posterior vitreous detachment (PVD).
- Higher incidence of primary open angle glaucoma (POAG).
- Divergent squint.

TREATMENT

I. *Glass*

i. The weakest possible concave lens with which the patient maintains 6/6 (or 20/20) distant vision is prescribed for constant wear.

ii. The subject is advised to hold near work at ordinary reading distance.

iii. Myopia should preferably be under corrected.

iv. In myopics, the presbyopia sets in at a later age depending on the strength of myopia. So, weaker lenses may be advised for near work for presbyopic correction.

v. Myopes should wear their spectacles close to the eyes.

II. *Contact lens—It offers the following advantages over spectacles wear;*

i. Wider field of view.

ii. Larger image size since it is worn closure to eyes than glasses.

iii. Cosmetic attraction.

iv. Elimination of image distortion through peripheral part of glasses.

v. May arrest progression of myopia in some cases–claimed by orthokeratology.

III. *Surgery, i.e. Refractive Surgery*

i. LASIK/LASEK is the most popular choice and is undertaken if the following conditions are fulfilled:

- The patient must be more than 18 years of age.
- The refractive error must be stable for 2/3 consecutive examinations at an interval of 6 months.
- Corneal thickness should not be less than 500μ.

- Peripheral retinal degenerations will not lead to retinal detachment.
- The refractive error is between –2.00D to –12.00D.

ii. Phakic intraocular lens–Here a foldable, thin IOL of appropriate power is implanted in the posterior chamber between the iris and the crystalline lens. It is fast gaining popularity and is particularly suitable in myopia of above –12.00D.

iii. Intracorneal ring (stromal), radial keratotomy and PRK are the other surgical options.

iv. FUKALA'S operation–Extracapsular removal of clear lens if the myopia is of –21.00D will render the patient aphakic. However, parallel rays of light will be focussed on or near the retina without any correcting lenses.

IV. *General Instructions*

i. Spectacles should be worn close to the eyes and worn constantly.

ii. Near work/reading should be done at ordinary reading distance in good illumination.

iii. Improvement and maintenance of good general health, e.g. nutritious balanced diet rich in green vegetables.

iv. Sports involving close physical contact to be avoided.

v. Low visual aid may be used in patients with low visual, acuity i.e. patients with pathological myopia.

vi. Genetic counselling.

ASTIGMATISM

TYPES

Based on relative position of image of distant object on the retina (Fig. 9-4).

a. Simple astigmatism–Here one image is located in the retinal plane and based on the location of the other image it may be:
   - Simple myopic astigmatism–The other image is located in front of the retina (A in Fig. 9-4).
   - Simple hypermetropic astigmatism–The other image is located behind the retina (B in Fig 9-4).

b. Compound astigmatism–Here both the images are either in front of the retina or behind the retina and designated as:
   - Compound myopic astigmatism (C in Fig.9-4).
   - Compound hypermetropic astigmatism (D in Fig.9-4).

c. Mixed astigmatism–Here one image is formed in front of the retina and the other image is located behind the retina (E in Fig. 9-4).

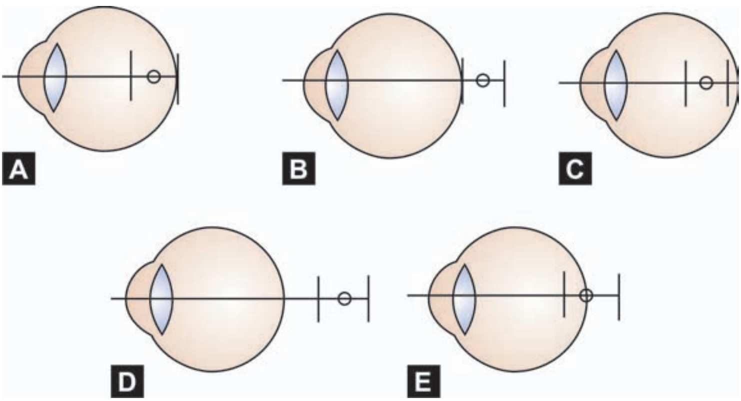


Fig. 9-4: Types of astigmatism, O = Circle of least diffusion

Based on angle between the two principal meridians of maximum and minimum curvature

a. Regular astigmatism–Here two principal meridians of maximum and minimum curvature are positioned at right angles, i.e. 90° to each other.

b. Irregular (or Bi–Oblique) astigmatism– Here two principal meridians of maximum and minimum curvature are positioned to each other at angles other than 90°. It is very uncommon and found in keratoconus, scarred cornea and after penetrating keratoplasty.

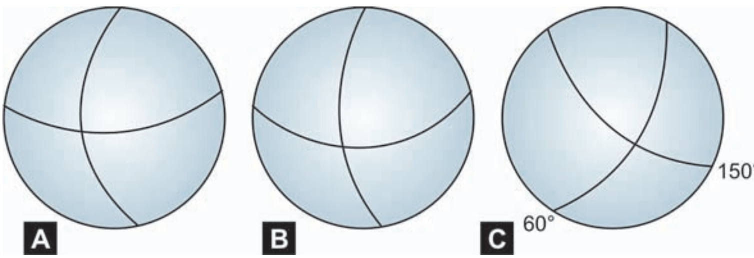
Based on Aetiology

A. Orientation of maximum curvature of cornea

   a. Astigmatism with–the–rule (or direct)–Usually vertical corneal meridian is more curved than horizontal one due to pressure of the eyelids on the eyeball. So, astigmatism in which the refractive power of the vertical or near vertical meridian is maximum is called astigmatism with-the-rule (Fig.9-5A).

b. Astigmatism against-the-rule (or inverse or indirect)–Here the corneal curvature in horizontal meridian is greater than the vertical one, i.e. the refractive power of the horizontal or near horizontal meridian is the maximum (Fig. 9-5B).

c. Oblique astigmatism–Here the radius of curvature of maximum and minimum curvature are aligned at 90° to each other but the two principal meridians are neither near horizontal nor near vertical (Fig. 9-5C).



Figs 9-5A to C: Types of astigmatism based on orientation of maximum curvature of cornea. (A) = With-the-rule, (B) = Against-the-rule and (C) = Oblique

B. Lenticular astigmatism–It is due to:

a. Curvature–It is due to variations in the curvature of one or both surfaces. Lenticular astigmatism is typically against the rule and it tends to neutralise the corneal astigmatism.

b. Index–It is due to inequalities of refractive index in different sections of the lens. It is seen in early cataract and is the reason of polyopia in early cataract.

c. Displacement of the refractive element of
   i. crystalline lens, i.e. subluxation.
   ii. decentration or tilting of pseudophakos (IOL).

C. External pressure on the cornea or globe

a. Chalazion or lid tumour.

b. After scleral buckling in retinal detachment surgery.

D. Diseases of the cornea
   a. Pterygium
   b. Keratoconus
   c. Corneal scarring, etc.

OPTICS OF ASTIGMATISM

A regularly astigmatic surface have a toric curvature and have the following features:

i. The maximum curved meridian have greater refractive power than the least curved one.
ii. If parallel rays of light fall upon a convex astigmatic surface the vertical rays will come to a focus earlier than the horizontal rays.
iii. However, both the vertical and the horizontal rays after refraction will be perfectly symmetrical in their planes but they will have two foci.
iv. The whole bundle of rays is termed "STURM'S CONOID". The distance between the two foci is termed "Focal interval of STURM". At a point the vertical and horizontal rays symmetrically diverge and converge respectively to form a circle on section. This is termed as the "Circle of least diffusion" (Figs 9-4 and 9-6).

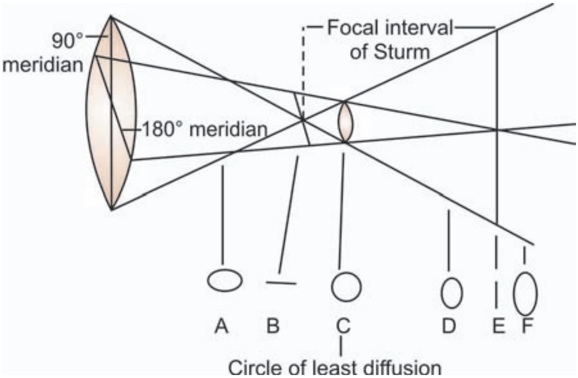


Fig. 9-6: Formation of Sturm's conoid in astigmatism. Cross sections of the conoid are shown at A,B,C,D,E and F.C represents circle of least diffusion

It is not uncommon to detect significantly good distant vision in presence of high mixed astigmatism. This surprising fact occurs because the circle of least diffusion falls upon or near the light sensitive layer of the retina.

SYMPTOMS

i. Diminished distant visual acuity–This is least in mixed astigmatism
ii. Eye strain or asthenopia–It is often more common and worse in lower degree of astigmatism than the higher one. This is due to effort of the eye to accommodate so that the circle of least diffusion falls upon or near the retina
iii. Headache and eyeache
iv. Blurring of letters while reading.

DIAGNOSIS

Objective

i. Retinoscopy
ii. Keratometry
iii. Placido keratoscopic disc–This test reflects irregularities on the corneal surface. The examiner looks through a hole in the centre of the disc, with alternatingly painted black and white circles, at the corneal image reflected from a light behind the patient.
iv. Computerised corneal topography.

Subjective

i. Astigmatic fan (Fig. 9-7)–It is used to measure the strength of the cylindrical lens and it's axis. The end point of cylindrical lens correction is achieved when the outline of the whole fan becomes equally clear and sharp. The axis of the cylinder is at right angles to the line which was initially most clearly defined.
ii. Stenopaeic slit test–In this test the slit is rotated till the patient sees the chart clearest. Then required spherical lenses are added. Then the slit is rotated 90° and again vision is adjusted

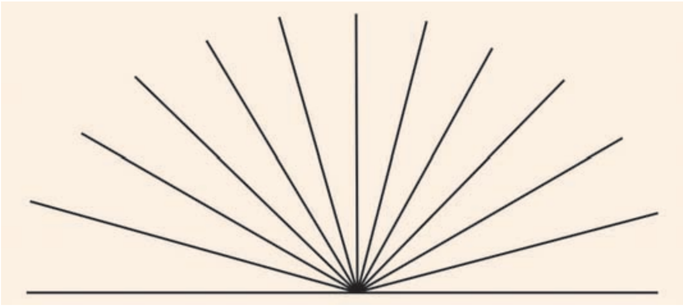


Fig. 9-7: Astigmatic fan

with spherical lenses. This stenopaeic slit only allows light in the axis of the slit to enter the eye. Thus, when its axis coincides with one of the principal axis of the eye, blurring is eliminated. The algebric difference between the two spherical correction equals the power/strength of the cylindrical lens and its axis is determined by the initial direction of the slit.

iii. Jackson's cross cylinder test (JCC test)–This test is discussed in detail in chapter–10.

ANISOMETROPIA

It is a situation in which refractive status of the two eyes are different, i.e. unequal. However, an insignificant difference in refractive status of the eyes is quite common.

AETIOLOGY

a. *Hereditary*–It is due to congenital cataract, congenital glaucoma, etc.
b. *Acquired*–It is due to surgical or nonsurgical trauma, unilateral aphakia and inequality in the rate of refractive changes in both eyes.

CLASSIFICATION

I. Based on refractive error

   a. Isoanisometropia–Here refractive status of both the eyes are either hypermetropic or myopic.
   b. Antimetropia–Here refractive status of one eye is myopia and the other is hypermetropia.

II. Based on dioptric difference–Patients symptoms vary significantly with the degree of dioptric difference between the two eyes
   a. Low = 0 to 2.50D
   b. High = 2.50D to 6.00D
   c. Very high = > 6.00D

In low anisometropia binocular vision is easily achieved and full optical correction is well-tolerated. A difference of 0.25D produces 0.5% difference in size of the retinal images of the two eyes. A difference of upto 5% of retinal image size is well-tolerated and two images can be fused without strain. So, a dioptric difference of more than 2.50D will lead to binocular vision problem and eye strain. Often the vision becomes uniocular and the worse eye becomes lazy, i.e. amblyopic and convergent if corrective measures are not undertaken in childhood.

OPTICAL PROBLEMS/DIFFICULTIES OF ANISOMETROPIA

a. *Binocular vision:* > 2.50D of difference in dioptric strength between the two eyes leads to eye strain due to effort of fusion. Binocular vision is not possible with spectacle correction if the anisometropia is > 4.00D.
b. *Amblyopia:* Often a difference of > 2.00D in hypermetropic patient is sufficient to induce amblyopia in the more hypermetropic eye. However, in myopic patients with anisometropia amblyopia is less likely to develop unless the difference is very significant.
c. *Squinting:* Convergent squint in childhood and divergent squint in adults.
d. *Diplopia:* It develops due to difference in image size of > 8%.
e. A difference in stimulus to the accommodation between the two eyes.

f. A difference in prismatic affect and distortion between the two eyes on looking through the spectacles obliquely, i.e. away from the optical centres.

TREATMENT

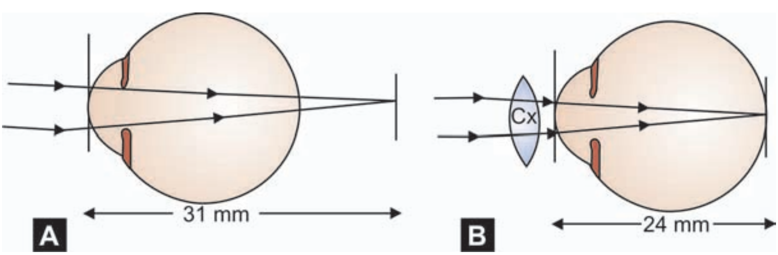
a. LASIK/LASEK
b. Contact lenses
c. Iseikonic lenses
d. If the patient is amblyopic (anisometropic amblyopia)–treatment of amblyopia.

APHAKIA

Aphakia means absence of the crystalline lens in it's normal anatomical position.

OPTICS

In aphakia the eye consists of a curved surface, i.e. cornea (radius of curvature–8.00mm) in between two media of different refractive indices (air = 1, aqueous and vitreous humour = 1.33). The anterior focal distance is 23 mm and the posterior 31 mm, as opposed to 15 mm and 24 mm respectively in an emmetropic eye. The absence of lens leads to extreme hypermetropia (Fig. 9-8A) and loss of accommodation. If the eye was previously emmetropic, the correcting convex lens in spectacle required to focus the image on the retina is estimated to be approximately +10.00D (Fig. 9-8B).



Figs 9-8A and B: (A) Optics of aphakia, (B) Correction of aphakia by + 10.00D convex lens (C_x)

SYMPTOMS

a. Blurring of vision for both distance and near
b. History of cataract operation or injury
c. Patient may wear very thick convex glass.

SIGNS

If extracapsular (ECCE)/intracapsular (ICCE) cataract extraction is done:

- Vision is finger counting at few feet without glasses.
- Upper limbus—Presence of linear scar with or without sutures (10′0′ nylon—Usually interrupted/continuous) may be seen.
- Anterior chamber depth–Deep.
- Iridodonesis, i.e. tremulousness of iris due to lack of support.
- Peripheral button hole iridectomy (PBHI) may be seen.
- Pupil–Jetblack due to loss of IIIrd and IVth Purkinje image (in ICCE) and IIIrd image (in ECCE).
- Ophthalmoscopy–The optic disc is very small.

TREATMENT

Spectacles

Spectacles are usually advised after 6 weeks of surgery. The time is required for complete wound healing and stabilisation of refractive error particularly astigmatism. If the patient was previously emmetropic usual prescription for glasses will be roughly as follows:

Glasses advised Right Eye = +10.00DSPH with +2.00 DCYL 180° (astigmatism with-the-rule)

Add: +3.00DSPH for near vision

The +3.00DSPH near addition is due to loss of accommodation due to absence of the lens. Aspherical lenticular resin lens (CR–39) is ideal for aphakic patients than crown glass lens.

Optical disadvantages of aphakic glasses:

i. Image magnification is 25–30%. So, in uniocular aphakia binocular vision is not possible due to aniseikonia. Hence, to avoid diplopia (where phakic eye vision is > 6/36), balanced (+10.00D) or frosted glass is dispensed for the phakic eye. The image magnification causes objects to appear closer to the eye then they are really.

ii. Spherical aberration–Pincushion distortion (see chapter - 7)
iii. Jack-in-the-box phenomenon–Due to prismatic aberration a ring scotoma is produced all around the edge of the lens. This causes an unseen object to suddenly pop up in front of the eyes or disappear into the ring scotoma, as the patient moves his eyes.
iv. Restricted visual field.
v. Lack of physical coordination which results from image magnification, restricted visual field, pincushion distortion and Jack-in-the-box phenomenon.
vi. Thick, heavy lenses are cosmetically deficient.
vii. Loss of lens often leads to coloured vision due to lack of natural filter offered by the lens. UV-A (315–400 nm) protection offered by the lens is lost.

Contact Lens

Advantages

All the disadvantages of glasses are neutralised:

i. Image magnification is 6–7%. Hence, binocular vision is possible in uniocular aphakia.
ii. Aberrations are lessened, i.e. pincushion distortion, etc.
iii. Increased visual field.
iv. Better physical coordination.
v. Cosmetically attractive.

Disadvantages

i. Inability of elderly patients to insert and remove contact lens efficiently.
ii. Foreign body sensation.
iii. Additional glasses required for reading correction. However, bifocal contact lenses are available and becoming increasingly popular.

Secondary IOL Implantation

Advantages

i. Image minification is 0–2%. Hence, quick return to binocularity is achieved due to minimum aniseikonia.
ii. Absence of aberrations.
iii. Restoration of normal peripheral field of vision.
iv. Excellent physical coordination.

Disadvantages

It is significantly reduced to usual complications following primary IOL implantation surgery, e.g. corneal decompensation, infection, astigmatism, etc.

Secondary IOL implantation in aphakia may be;

a. AC IOL implantation in aphakia following intracapsular cataract extraction (ICCE)–If the aphakic eye was emmetropic earlier, AC IOL of +18.00D strength is required to focus the image on the retina.
b. PC IOL Implantation in aphakia following extracapsular cataract extraction (ECCE) - +20.00D strength of PC IOL is required to focus the image on the retina.
c. Hyperopic *LASIK*.

PSEUDOPHAKIA

Pseudophakia means replacement of the natural crystalline lens by a synthetic intraocular lens (IOL).

MATERIALS OF IOL

- Polymethyl Methacrylate (PMMA)
- Silicon
- Acrylic.

CALCULATION OF IOL POWER

It is done by:

- Axial length measurement by A-scan
- Keratometry
- Standard calculation formulas.

TYPES OF IOL

It depends on location/support of the IOL (Fig. 9-9).

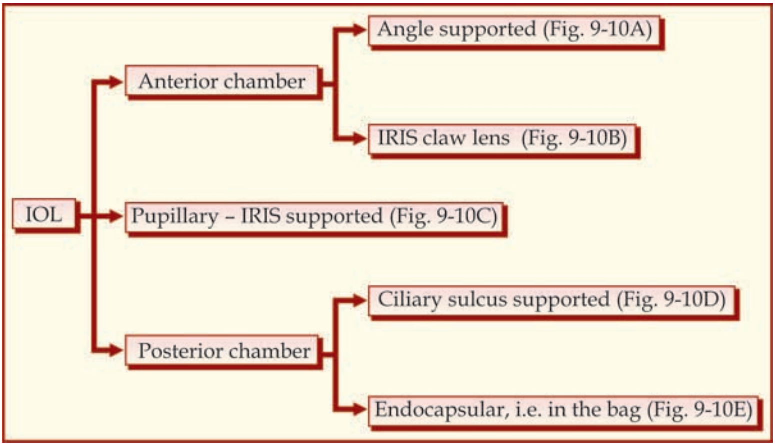
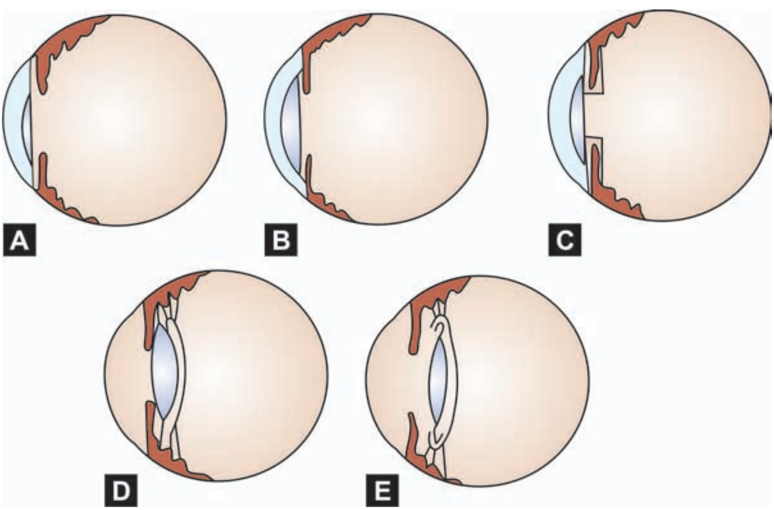


Fig. 9-9: Types of IOL (depending on support/location)



Figs 9-10A to E: Showing different types of IOL depending on location/support. (A) Angle supported lens, (B) IRIS claw lens, (C) IRIS supported, (D) Ciliary sulcus supported, (E) Endocapsular lens

Residual Refractive Error

Residual refractive error in pseudophakia consists of;

- Spherical error–Accurate biometry overcomes this error.
- Astigmatism–Phacoemulsification results in astigmatism against-the- rule, whereas PC IOL implantation with sutures results in astigmatism with-the-rule.
- Loss of accommodation–However, nowadays multifocal IOL's, accommodative IOL's are increasingly available to correct this error.

After phacoemulsification glasses may be advised after only one week and after small incision cataract surgery (SICS) glasses may be advised after 3 weeks. However, after ECCE with PC IOL implantation glasses are advised only after 6 weeks.

PRESBYOPIA

Presbyopia is defined as the slow, gradual, age-related and irreversible decline in the physiological process of amplitude of accommodation, i.e. recession of near point beyond comfortable near work and reading distance. The condition becomes first noticeable, clinically, usually between the ages of 38 and 42.

AETIOLOGY

Lenticular Theories

Fincham theory and Hess-Gullstrand theory

- Increase in hardness and consequent decline in plasticity of the lens nucleus as part of an ageing process.
- Decline in elasticity of the lens capsule.

These two factors contribute to requirement of more energy to deform the lens material with increasing age. The lens becomes more resistance to change in the shape age as advances.

Geometric theory

- Increase in size and curvature of the lens
- Change in orientation of the zonules due to shifting of zonule insertions. Following ciliary muscle contraction the zonular relaxation leads to less radial force of tension on the surface of the lens capsule.

- So, the zonular relaxation has lesser effects on the change in shape of the lens.

Extralenticular Theory

- Weakening of the ciliary muscle (Duane theory)
- Progressive deterioration in the elastic components of zonules and ciliary body.

The aetiology of presbyopia possibly is multifactorial. In recent years restoration of accommodation by implantation of an accommodative IOL in the capsular bag is demonstrated clinically. So, lenticular origin of presbyopia (Fincham theory) along with geometric theory seems most acceptable and scientific.

SYMPTOMS

- Blurring of vision particularly small prints, in the evening or in dim light, at the normal reading distance.
- Eyestrain and headache after close work.
- Reading materials are held at a distance further away from the normal position.

TREATMENT

Spectacles

Prescription of appropriate corrective convex spherical lens to bring the near point within normal reading distance. The following steps are followed;

i. Correction of distance power of each eye separately (static refraction).
ii. Addition of appropriate convex lens to both eyes for near work. Minimum near correction glass is +0.75DSPH. Usually following standard notation table is followed while correcting presbyopia (Table 9-1).

Contact Lens

Various types of bifocal contact lenses are available for presbyopic correction.

Table 9-1: Standard notation table for presbyopia correction. The glasses may be unifocal, bifocal, progressive addition lens or multifocal

Age of the patient	*Near addition prescribed*
40	+1.00 DSPH
42	+1.25 DSPH
45	+1.50 DSPH
47	+1.75 DSPH
50	+2.00 DSPH
52	+2.25 DSPH
55	+2.50 DSPH
60	+2.50 DSPH to +3.00 DSPH
Aphakia	+3.00 DSPH
Pseudophakia	+2.50 DSPH to +3.00 DSPH

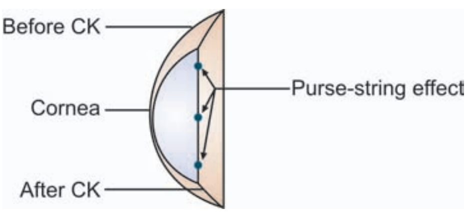


Fig. 9-11: Optical principle of conductive keratoplasty (CK)

Surgical (Conductive Keratoplasty)

Conductive keratoplasty (CK) is based on the principle of thermokeratoplasty, using radiofrequency energy. Conductive keratoplasty creates a purse-string effect that steepens the central cornea through collagen shrinkage that encompasses 80% of the corneal thickness (Fig. 9-11).

CHAPTER 10

Estimation and Correction of Refractive Errors

INTRODUCTION

The methods employed in measuring and correction of refractive errors consist of:

I. Initial estimation by objective methods—Objective method refers to preliminary estimation of refractive error without any verbal response from the patient. However, some co-operation from the patient such as steady fixation is required. Objective methods are:
   i. Retinoscopy (plane mirror or streak)
   ii. Autorefractometry
   iii. Photo refraction.

II. Subjection methods—Subjective method refers to refinement of refractive error estimated from objective method, to obtain best visual acuity. Subjective method requires verbal response from the patient. However, subjective method cannot be used for patients who cannot speak or are unable to respond. In those cases, the practitioner must rely on objective methods only.

RETINOSCOPY

It is the most common objective method used for estimation of refractive error, with accommodation at rest. It involves a study of the movements of the retinal image produced by a patch of light on the patient's retina, through a peephole in the centre of the mirror. Retinoscopy can be done by either a plane mirror or a streak retinoscope.

RETINOSCOPY WITH PLANE MIRROR–PROCEDURE

a. *Cycloplegia*–It is required in children and young subjects. In adults and older patients it is usually not required unless the pupil is very small. Cycloplegia in children (upto 6 years of age) is achieved by application of atropine sulphate (1%) eye ointment 2 times daily for 3 consecutive days prior to the day of examination. In older children and adults tropicamide (1%) eyedrop is applied 2 or 3 times at interval of 5 minutes and retinoscopy should be conducted between 20–30 minutes of the last application.
b. It is done in a *dark room*–The refractionist sits 1 metre away from the patient. The patient, with the trial frame on, is asked to look at the distance. The retinoscopy light is positioned behind and to the right of the head of the patient.
c. The refractionist looks through the central peephole of the retinoscopy mirror and reflects the light on the patient's pupil.
d. The mirror is tilted very slowly vertically and horizontally and the movement of the shadow in the pupillary area is observed.
e. Depending on the refractive status of the patient's eye the shadow will behave in relation to the tilting of the mirror as follows:
   i. In myopia of > 1.00D–The shadow moves in the opposite direction. This is called "against the movement".
   ii. In myopia of –1.00D–There is absence of shadow. The pupil will be either totally dark or illuminated. This is called "point of reversal/point of neutralisation".
   iii. In hypermetropia, emmetropia and myopia of < 1.00D–The shadow moves in the same direction. This is called "with the movement".
f. If the refractionist observes "against the movement", point of reversal can be achieved by adding increasingly concave (minus) lenses from the trial set in the trial frame. If the refractionist observes "with the movement" point of reversal can be achieved by adding increasingly convex (plus) lenses from

the trial set in the trial frame. Speed and brightness of the retinoscopy reflex/shadow increases as point of reversal is approached.

g. The procedure of point of reversal is done in both vertical and horizontal meridians separately in each eye. In spherical refractive errors the point of reversal will be the same in both the meridians. In astigmatism, the point of reversal will be different in both the meridians. In astigmatism with oblique axes, the mirror is tilted aligning with the oblique axes.

h. In patient's with high refractive errors the reflex/shadow is faint and the movement is often so slow it is quite difficult to discern. In this situation, try a high convex lens or a high concave lens to ascertain the nature of the movement. If the refractionist sits at 1 metre away from the patient and the light source, the point of reversal is –1.00D, i.e. the patient is –1.00D myopic with the addition of the lens required for neutralisation of movement. However, it is often convenient for the refractionist to hold the lens in his left hand instead of trial frame and perform the retinoscopy. Here, he sits at arm's length distance from the patient, i.e. 2/3rd of a metre. The point of reversal will be then –1.50D.

Calculation of Refractive Error Based on the Retinoscopy

It is calculated from the simple formula:

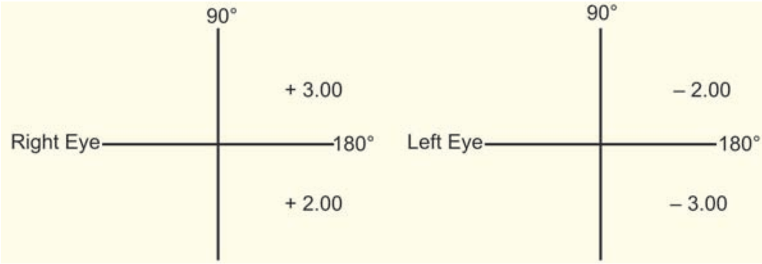
$$RE = \frac{1}{-d} + D + A$$

RE = Refractive error; d = Distance in metres of the retinoscope from the patient's eye; D = Power of the lens in diopter in trial frame at the point of reversal; A = Accommodation in diopters (accommodation is zero in static retinoscopy).

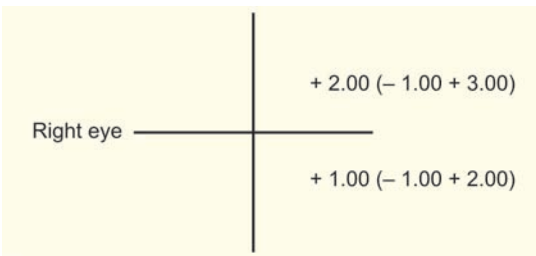
i. If the point of reversal is + 3.00D in 1 metre static retinoscopy, the refractive error will be – 1.00D + 3.00D = + 2.00D.

ii. If the point of reversal is – 4.00D in 2/3rd metre static retinoscopy, the refractive error will be – 1.50D –4.00D = – 5.50D.

iii. In case of astigmatism, i.e. where the point of reversal is different in two meridians, it is calculated as follows—



(Conventionally, the retinoscopy finding is recorded as above) The point of reversal is marked in a cross as above. So, in the right eye the refractive error will be calculated from the optical cross drawn below;



The final refractive error is calculated from the formula given below:

The ***power of the sphere*** = *lower value ignoring the sign*

Axis of the cylinder (Astigmatism) = *the meridian of the sphere*, i.e. the lower value

The **power of the cylinder** = deduct the lower value from the higher value keeping the signs intact.

So, in right eye the refractive error will be + 1.00DSPH with + 2.00 – (+ 1.00) DCYL 180° = + 1.00 DSPH with + 1.00DCYL 180°.

So in left eye the refractive error will be –3.00DSPH with – 4.00– (– 3.00) DCYL 90° = – 3.00DSPH with – 1.00DCYL 90°.

RETINOSCOPY WITH STREAK RETINOSCOPE

Modern retinoscopes are fitted with a long straight filamented bulb in order to produce a bright streak shaped object. Parts of a streak retinoscope are (Fig. 10-1):

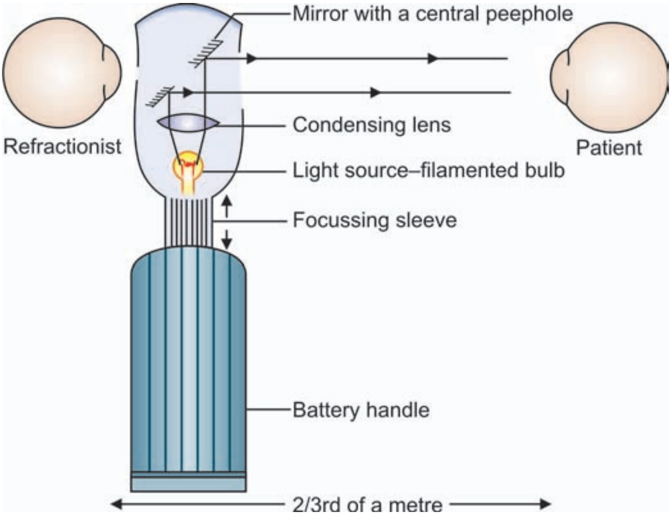
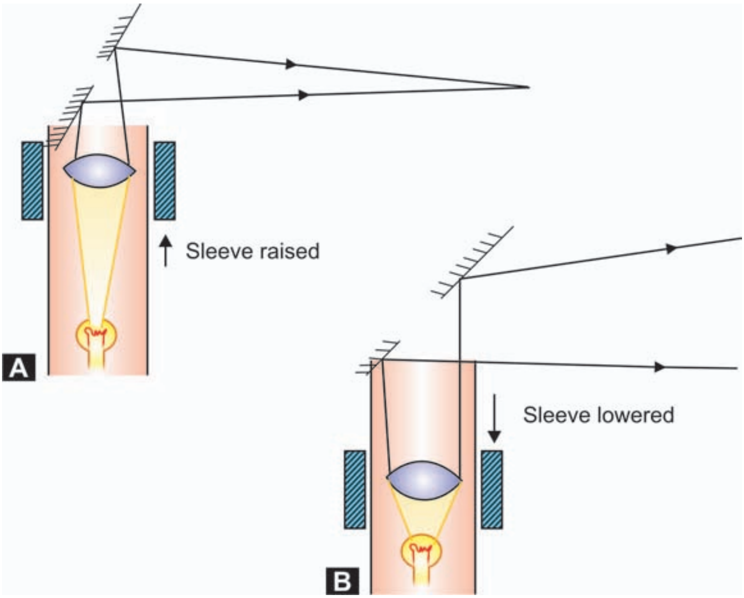


Fig. 10-1: Streak retinoscope with parts

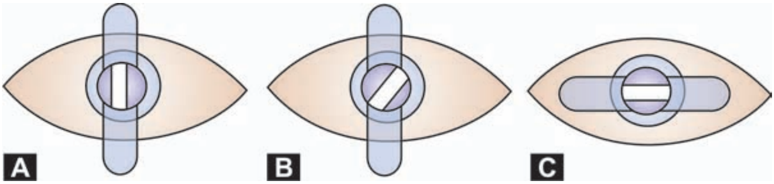
i. Battery handle (to accommodate the batteries).
ii. Light source–A bulb with long straight filament.
iii. Condensing lens–It forms an image of the filament and focusses onto the mirror.
iv. Mirror with a central peephole–It is located in the head of the streak retinoscope and is oriented at an angle of 45° to the axis of the handle. It reflects the streak of light from the condensing lens towards the patient's pupil.
v. Focussing sleeve–It changes the distance between the bulb and the condensing lens to project either divergent rays (to produce plane mirror effect) or convergent rays (to produce concave mirror effect). Width of the streak varies as the sleeve is raised or lowered (Fig. 10-2). In some retinoscopes the bulb is moved (Copeland) while in others the condensing lens is moved (Welch Allyn, Keeler, etc.) by the focussing sleeve. The sleeve is also turned to rotate 360° the streak of rays in different meridians. The plane mirror effect is usually used in streak retinoscopy.



Figs 10-2A and B: Streak retinoscope–use of focussing sleeve to obtain. (A) Concave mirror effect, (B) Plane mirror effect

Retinoscopy with Streak Retinoscope–Procedure

a. Set the focussing sleeve in lowest position in Welch Allyn, Keeler streak retinoscopes and in upper most position in Copeland streak retinoscope to get plane mirror effect.
b. It is convenient for the refractionist to work at a distance of 66 cm (or 2/3rd of a metre or 26″), which corresponds to an arm's length, in streak retinoscopy. This implies a working lens of + 1.50D. Some refractionist uses a working distance of 50 cm i.e. ½ metre with a working lens of + 2.00D.
c. The patient is asked to look at a fixation point at least 15′ from the eye.
d. The streak is aligned vertical by rotating the focussing sleeve.
e. Now observe the retinal reflex/shadow and it will appear as in Figure 10-3A. if oblique astigmatism is absent. If oblique astigmatism is present, the retinal reflex will appear as in Figure 10-3B, where the reflex within the pupil is not aligned vertically.



Figs 10.3A to C: (A) Oblique astigmatism absent (horizontal axis), (B) Oblique astigmatism present, (C) Oblique astigmatism absent (vertical axis)

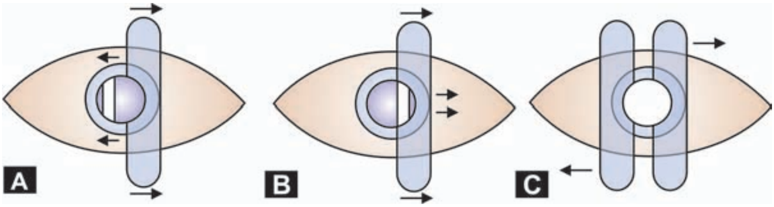
f. Tilt the vertical streak horizontally across the pupil and notice whether the reflex in the pupillary area moves in the same direction as the streak or in the opposite direction.

g. Rotate the focusing sleeve until the streak is horizontal (Fig. 10-3C) and tilt the streak vertically across the pupil and notice whether the reflex in the pupillary area moves in the same direction as the streak or in the opposite direction.

h. Depending on the refractive status of the patient the reflex will behave as follows:
   i. In myopia of >1.50D–The reflex and the streak moves in the opposite direction (against the movement–Fig.10-4A)
   ii. In myopia of –1.50D–It is the point of reversal, i.e. neutralisation. The *streak disappears* and the pupil is *flooded with light*. There is absence of against the movement or with the movement (Fig.10-4C)
   iii. In hypermetropia, emmetropia and myopia of < 1.50D–the reflex and the streak moves in the same direction (with the movement (Fig.10-4B)

i. Point of reversal is confirmed by:
   i. Lean forward a little towards the patient and definite "with the movement" appears and move a little away from the patient and definite "against the movement" appears.
   ii. Put an additional + 0.25D lens in the trial frame and "against the movement" appears.

j. If "with the movement" is observed, add increasingly convex lenses until point of reversal is reached. Similarly, if against the movement is observed, add increasingly concave lenses until



Figs 10.4A to C: (A) Against the movement, (B) With the movement (C) Point of reversal

point of reversal is reached. The procedure is done in both vertical and horizontal meridian. The speed, brightness and width of the retinal reflex increases as the refractionist approaches the point of neutralisation.

k. In case of oblique astigmatism the streak is aligned with the retinal reflex and the procedure is continued as discussed above. The point of reversal is estimated in one meridian first and the point of reversal is estimated 90° away in the second meridian.

l. Determination of the axis (principal meridians) in astigmatism– Axis is determined by the following factors:

   i. Break–When the streak and the retinal reflex are not parallel, i.e. the streak is not aligned with a principal meridian, break is observed (Fig. 10-5). When the reflex is aligned with the streak the break disappears.

   ii. Width–The reflex is narrowest when the streak aligns with a principal meridian. The width of the reflex increases when the streak is rotated to either side of the actual axis.

   iii. Brightness–The reflex is brightest when the streak is aligned with the correct axis. Hence, when the streak is properly aligned with the axis, the break disappears and the reflex becomes narrowest and brightest.

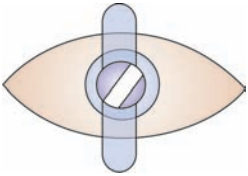


Fig. 10-5: Observation of break

Static retinoscopy is used for estimation of refractive error. In static retinoscopy, it is assumed that the accommodation is nil, when the patient is asked to look at a distant fixation point.

Dynamic retinoscopy is used to estimate accommodative response. Hence, in dynamic retinoscopy the patient is asked to fixate at a near fixation target. The near fixation target may be words, shapes etc. which is appropriate for the age of the patient. These can be fitted onto the streak retinoscope. Dynamic retinoscopy also provides refractive information, adequacy of cycloplegia and may help to decide amblyopic therapy.

AUTOREFRACTOMETRY

It is a very precise objective automated electronic method to measure refractive error. They can be operated either manually or in automatic mode. The autorefractometers work on the basic principal of retinoscopy and Badal optometer. The patient is asked to look at a visible coloured fixation target. The refractionist aligns the instrument panel to sharp focus and pushes a button which initiates the process of estimation of refractive error. An inbuilt microprocessor analyses the focal power of emitted rays from the patient's eye and processes it into accurate refractive error correction in diopters in few seconds. Usually 3 readings in each eye are averaged to give a final assessment in a print out. Modern autorefractometers are very quick and accurate.

PHOTOREFRACTION

It is an objective method of measurement of refractive errors by employing photographic method. It is ideal in patients who cannot maintain fixation, e.g. in infants and mentally unstable. However, it is less accurate than retinoscopy and autorefractometry.

SUBJECTIVE REFRACTION

The assessment of objective methods are further refined by subjective methods. If cycloplegia is used in objective (retinoscopy) method the subjective method is tested after the effect of cycloplegia wears off. Hence, often it is termed as postcycloplegic test/post-mydriatic test.

PROCEDURE

i. Each eye is tested separately, the other eye being blocked. The right eye is conventionally tested first for subjective refraction.
ii. Spherical error is corrected initially by appropriate spherical lenses and then the astigmatism is corrected by appropriate cylindrical lenses. This is done by refining the refractive errors obtained by objective method. Correction for astigmatism will be discussed later in this chapter in details.
iii. As a rule, hypermetropia is corrected with strongest convex lens and myopia is corrected with weakest concave lens to achieve best corrected visual acuity.
iv. Next step is binocular balance to eliminate differences in accommodation between the two eyes during monocular subjective refraction.
v. Binocular subjective refraction–It is initiated by using more convex lens or less concave lens than the patient's refractive error assessed by monocular subjective refraction. It is termed as "fogging method" and it is employed to relax accommodation. The eyes are made artificially myopic by addition of high convex lens or less concave lens to form an image in front of the retina. Any effort by the patient to accommodate will result in a poorer image and relaxation of accommodation is thus achieved. Now the convex lens power is gradually reduced or the concave lens power is gradually increased by the small fraction, e.g. 0.50D until best visual acuity is reached. The whole exercise of reducing convex power or increasing concave power is done by keeping the earlier lens in place until the next is in place in the trial frame. Then the earlier lens is removed. This is done to prevent accommodation becoming active again.
vi. Then, the addition for near vision is tested (if required) monocularly and binocularly.
vii. Finally, the spectacle is prescribed with necessary instructions for the optician and the patient. A model specimen of final prescription is written as discussed later in this chapter.

PRESCRIPTION FOR SPECTACLES

- The *spherical strength* of power is first mentioned, e.g. +1.75DS (Diopters of Sphere) or + 1.75DSPH (Diopter Spherical).
- The *cylindrical strength* of power is quoted next. This is followed by multiplication sign and degree of the axis, e.g. + 1.25 DC (Diopters of cylinder) or + 1.25 DCYL (Diopter cylindrical) × 90° (arrow indicates the direction of the axis as per standard international convention).
- This is followed by the corrected visual acuity.
- However, to simplify DS/DSPH, DC/DCYL and the degree sign are often deleted.

SAMPLE OF PRESCRIPTION

Name: - Age: - Sex: -

Address: -____

Glasses advised

Right Eye (or OD) = + 1.75 DSPH with + 1.25 DCYL X 90° ↓6/6 (or 20/20).
Left Eye (or OS) = + 1.25 DSPH with + 0.75 DCYL X 60° ↓6/6 (or 20/20).
For Near Vision add + 1.75 DSPH to both eyes (OU) N_6

OR

EYE	RIGHT (OD)				LEFT (OS)			
	DSPH	DCYL	AXIS	VISION	DSPH	DCYL	AXIS	VISION
DISTANCE								
NEAR								

Specifications
- Unifocal/Bifocal/Trifocal/Progressive addition lens (PAL).
- Crown glass/CR–39/Polycarbonate lens.
- A.R. Coating/Photochromatic/Colour tint/Hard coating.

Remarks: - For constant/distant/near wear.
P.D………………. mm
Date:

Signature
(Name of the Eye specialist/
Refractionist in capital letters).
Regn. No.:

N.B. Please bring this prescription during future eye check-up.

The axis of the cylinder is marked in each trial lens. The trial frames are also marked as per standard international convention from 0° to 180°.

SPECIAL TESTS TO CONFIRM SUBJECTIVE REFRACTION (OPTIONAL)

Jackson's Cross Cylinder Test (JCC test)

It is the most common and reliable procedure proposed by Edward Jackson for refining astigmatic correction. It's principle is based on placing the "circle of least diffusion" on the retina. Cross cylinder is a spherocylindrical lens with equal powers in principal meridians and opposite in sign. In cross cylinder the power of the cylinder is double the power of the sphere and of opposite sign. This results in superimposition of two cylindrical lenses of equal power of opposite sign with their axes at right angles to each other. The Jackson cross cylinder is mounted on a handle which is aligned at 45° to the axes of the cylinders (Fig. 10-6). The power of each cylinder actually lies at right angles to the marked axis and actually coincides with the marked axis of no power of the other cylinder with opposite sign (Fig. 10-6). The cross cylinders are designated by the strength of the cylinder and is marked on the handle. Hence, the cross cylinder in Figures 10-6 will be named as 0.50 cross cylinder.

Cross cylinder serves following purposes:

- To verify the axis of the trial cylindrical lens.
- To check the power of the cylindrical lens in the trial frame.
- To verify if any cylindrical correction is necessary.

1.00D cross cylinder is employed in patient's with poor visual acuity, whereas 0.50D cross cylinder is employed in patient's with good visual acuity. Jackson's cross cylinder test is done in two stages:

i. Verification of axis of the cylindrical lens–the patient is asked to look at the Snellen's test types, two lines above the smallest line he can identify. The test starts with the patient having best monocular refractive correction on the trial frame. The cross cylinder is held in front of the trial cylindrical lens with its handle aligned with the axis of the trial cylinder lens.

The cross cylinder is then flipped about and the patient is asked which position gives a better visual acuity. By the process of flipping the concave power principal meridian of the cross cylinder becomes convex power principal meridian, and *vice versa*. If the axis of the trial cylinder lens is incorrect, one flip position will give a clearer image than the other. The cross cylinder is held at a preferred position and the axis of the trial cylinder lens is rotated slowly towards the axis of the same sign on the cross cylinder. To locate the correct axis, the process is repeated, until the vision is equally clear for both flipped position of the cross cylinder.

ii. Verification of power of the cylindrical lens–the cross cylinder is held before the trial cylindrical lens with the axes aligning alternating. This will result in increase or decrease of the power of the trial cylindrical lens. The vision is equally clear for both flipped positions of the cross cylinder when the power of the trial lens cylinder is correct.

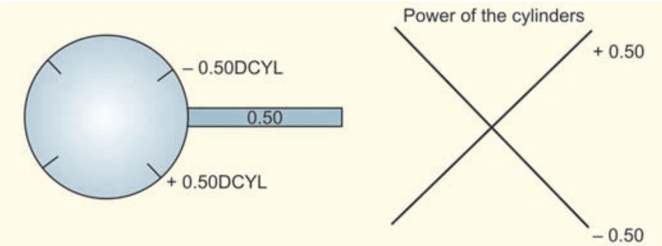


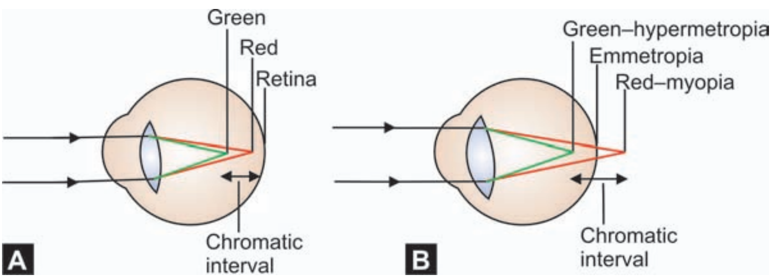
Fig. 10-6: Jackson's cross cylinder (JCC) with axis marking (on the left) and orientation of power of the cylinders (on the right)

Cross cylinder can also be used to verify absence of cylindrical correction. The cross cylinder is aligned in front of the spherical correction in four different positions with its axis at 45°, 90°, 135° and 180°. If the patient reports improvement of vision in any of these locations, additional cylindrical correction is required.

Duochrome Test

It is based on chromatic aberration of the eye. The test consists of two rows of black Snellen letters, silhouetted against illuminated coloured glass. The upper row is against a red glass background while the lower row is against a green glass. The duochrome test makes use of the chromatic aberration (longitudinal) of the eye to help correct the refraction near the middle of the visible spectrum. The subject is asked to view the letters by means of red and green light respectively. The subject can easily specify which is clearer. A myopic sees the red letters more clearly and the hypermetropic sees the green letter more clearly than the red.

The duochrome test begins with the addition of excess plus power. This shifts the chromatic aberration anterior to the retina. So, green light is refracted more than the red light by the eye (Fig. 10-7A). So, the red letters are more distinct than the green letters. The convex lens is now reduced gradually in 0.25D steps, with gradual posterior shifting of chromatic interval. The endpoint of the duochrome test is reached when the red and green letters are equally black and distinct, i.e. at the endpoint the red and green foci are dioptrically equidistant from the retina (Fig. 10-7B).



Figs 10.7A and B: (A) Beginning of duochrome test, (B) Endpoint of duochrome test

Subjective Autorefraction

Nowadays, subjective autorefractors are also available. However, they are not so convenient and are quite expensive. Further, good proportion of patients show more concave or less convex power than with the conventional subjective refraction. Frequently, they show more concave lens power in children probably due to accommodative effort.

Pinhole Test

It is a useful initial test to assess whether the diminished visual acuity is either due to refractive error or due to other causes. If the pinhole visual acuity (visual acuity through the pinhole) is significantly increased, the causal factor is definitely refractive error. If the pinhole visual acuity is same then the cause is ocular disease other than macular involvement. In macular disease the pinhole visual acuity is significantly reduced.

Accurate refraction is an art achieved through patience and experience. There are certain practical tips to avoid spectacle intolerance;

- Pseudophakic patients usually tolerate full astigmatic correction.
- It is inadvisable to advice larger degree of cylindrical correction to a patient who is not used to cylindrical correction earlier.
- It is inadvisable to overcorrect hypermetropia.
- It is inadvisable always to undercorrect myopia.
- It is not advisable to change prescription of glasses unless there is a gross refractive change.

Section 5

Practical Ophthalmics and Clinical Optometry

CHAPTER

11 Materials—Ophthalmic Lens and Spectacle Frame

OPHTHALMIC LENS MATERIALS

Glass, resin lens and polycarbonate material, with distinctive individual qualities, are used as ophthalmic lens. Since it's introduction in 1947, the resin lens is gradually capturing the larger market share in ophthalmic lens industry. However, introduction of polycarbonate is going to challenge it seriously.

GLASS

Glass is available in different refractive indices for ophthalmic use. Glass of 1.523 refractive index, termed crown glass, is most commonly used as ophthalmic glass for the following properties:

i. High level of transparency
ii. Colourless
iii. Resistance to heat
iv. Resistance to scratch
v. Good optics, i.e. very little distortion through the lens.

Glasses of higher refractive indices (1.70, 1.80 and 1.90) are thinner but heavier than resin lenses. High index lens is a specialised lens made with higher refractive material than crown glass. High index (1.8) lenses are used for correcting higher refractive errors as they can be made much thinner than crown grass lenses of equivalent dioptric strength.

Photochromatic glasses darken on exposure to bright sunlight. They become colourless again on removal for light. Photochromatic glasses are made by incorporating silver halide crystals within the glasses. Silver deposits form on the surface of the crystals within the lens on exposure to ultraviolet radiation between 320 and 420 nm and are responsible for darkening of the glass. When the glass is removed from the light, silver halide is reconverted and the lens becomes clear again.

Tints added to glass lens are permanent. Darkening and lightening of the tint on the glass is not possible.

Impact resistance can be imparted to glass lenses by chemical tampering or heat treatment or lamination. Chemical tempering of glass lens provides the best quality of optical glass lens with impact resistance. Heat-treated glass lenses are particularly unsafe due to the risk of spontaneous breakage.

RESIN LENS (OR RESILENS OR PLASTIC LENS)

Resin lenses are made from acrylic resins. These resin lenses are coated with harder coating material to render greater scratch resistance. Most popular resin material is called CR–39 (C = Columbia, indicating the company which developed it, R = Resin, 39 = it is developed on the 39th attempt). It is Allyl Diglycol Carbonate. It has refractive index of 1.498. It is a thermosetting material which can withstand heat upto 100°C. Resin lenses have the following advantages over ophthalmic glasses (Table 11-1):

i. It weighs only about half the weight of the glass.
ii. It is less fragile and offers more protection to the eyes against impact.
iii. Tints can be easily applied to these lenses. In addition, the tints can be lightened or darkened in a CR–39 lens with scratch free surfaces. Resin lens with scratch free surfaces can be bleached and fresh tint can be applied in the laboratory without any damage to the lenses.
iv. All lens styles are available in CR–39.
v. CR–39 lenses absorb UV rays upto 350 nm providing UV protection to the eyes and the adjoining surface areas. CR–39 with UV absorber blocks UV rays upto 400 nm.
vi. Fogging of lens in response to change in environment (from cold to warm) is considerably reduced in comparison to glass lens.

Disadvantages of Resin Lens

i. They are less scratch resistant than glass. However, special precautions like cleaning under warm running water followed by drying with soft cloth, avoiding friction against surface, reduce the risk of scratch. Specialised scratch resistant coatings will also help in reducing this problem.

ii. Resin lens is comparatively thicker than crown glass. So, the edge of high minus (concave) lens is often very conspicuous.

However, the advantages of resin (CR–39) lens outnumber it's disadvantages. Now, resin lenses of higher refractive indices than CR–39, such as 1.586, 1.60 and 1.66 are available. They are thinner and lighter like polycarbonate and cosmetically superior than CR–39 lenses. Tints can be easily applied. However, darkening or lightening of tints on high index resin lenses, may cause damage or discolouration of the lenses, as with the polycarbonate lenses.

POLYCARBONATE (OR POLY) LENS

Polycarbonate lenses are much superior than both glass and resin lenses and are destined to be the lenses of the future. It is a thermoplastic material, i.e. it softens when heated. It is supplied with a hard or scratch resistant coating. It is highly resistant to impact. It's refractive index is 1.586. So, it is thinner than CR–39 lenses. It has following properties (Table 11-1):

i. It is the thinnest and lightest lens material.

ii. It is strongly impact resistant, i.e. virtually unbreakable. Bullet proof vests are made up of this polycarbonate material.

iii. Visibility is slightly distorted around the edges.

iv. It scratches easily and needs a hard scratch resistant coating.

v. Polycarbonate lenses may shrink in very cold climate.

vi. It may crack or expand in hot climates.

vii. It is very difficult to add tint on polycarbonate lenses. Darkening or lightening of tints may occasionally damage the lenses or change the colour of the lenses.

viii. It blocks harmful UV rays upto 400 nm, i.e. both UV-A and UV-B.

Table 11-1: Comparison between crown glass, resin lens and polycarbonate lens

	Crown Glass	*Resin Lens*	*Polycarbonate Lens*
Refractive Index	1.523	1.498	1.586
Scratch Resistance	High	Less than glass	Scratches easily. However, hard coatings on both surfaces confer high scratch resistance
Lens thickness	Thinner than resin lens	Thicker than glass	Thinnest
Weight	Heavier	Lighter than glass (50%)	Lightest Lighter than CR-39 by 10%, lighter than glass by 60%
Impact resistance	Less	High, less fragile than glass	Highly resistant, i.e. virtually unbreakable
Surface reflectance at each surface	4.30	3.97	5.13
Abbé's number/ V–value	59	57.8	30
Tint	Permanent, lightening/ darkening is not possible	Tint is not permanent, lightening/ darkening is possible Retinting is possible	Very difficult to apply tint Darkening/lightening may damage the lenses
UV protection	Absorbs UV rays upto 300 nm	Absorbs UV rays upto 350 nm	Absorbs UV rays upto 400 nm
*Density (g/cm^3)	2.54	1.32	1.2

* The greater the density of an optical material, the greater it's weight

Due to high degree of impact resistance (virtually unbreakable), polycarbonate lenses are particularly advisable in following situations to prevent accidental injuries to the eye—

a. One-eyed patient–As a precaution against injury to the good eye.

b. Children–Since children are most vulnerable to accident and injury, it offers protection to the eyes.
c. Patients employed in hazardous industries.
d. Persons actively involved in sports, stuntmanship.

A new lens material called "TRIVEX" was introduced in 2002. It has followed properties:

i. Refractive index—1.53
ii. Impact resistance–It is comparable to polycarbonate.
iii. V-value-44
iv. Surface reflectance–At each surface is 4.4
v. UV protection–Absorbs UV rays upto 400 nm.
vi. Density–1.11

"TRIVEX" is the ophthalmic lens material of the future.

Constringence (OR Abbé's number or V–value)

It is a positive number which specifies any transparent medium and indicates the degree of transverse chromatic aberration. It is the reciprocal of the dispersive power of the lens material. A material with higher constringence value. ($V \geq 50$) produces less chromatic aberration. Crown glass have V -value of 59 while, CR–39 have V-value of 57.8. So, they usually do not give rise to complaint of colour fringing due to low dispersive power. However, polycarbonate and high index lenses have a lower V-value and cause colour fringing due to higher degree of dispersive power.

SPECTACLE FRAME MATERIALS

Spectacle frame is defined as a device to hold the spectacle lenses within it. A variety of materials are used for spectacle frame with distinctive individual properties, distinctive techniques of insertion of lenses and adjustment of the frames. Properties of ideal frame materials are as follows:

i. Rigidity
ii. Adjustability
iii. Economy
iv. Durability
v. Corrosion resistance from perspiration

vi. Convenient manufacturing process
vii. Cosmetically soothing and attractive
viii. Light weight
ix. Noninflammable.

The following types of frame materials are available:

METALLIC–ECONOMY (ALLOYS)

Stainless Steel

It is particularly suitable for rimless mount and temple parts of frames. However, it needs protection by electroplating or other suitable methods to prevent corrosion. Distinctive features of stainless steel frames are:

i. Frames made of stainless steel are more durable and flexible than an ordinary metal frame. The spring effect is an additional advantage for the wearer.
ii. It is suitable for patients who are susceptible to allergic reaction to ordinary metal frames.
iii. It is less tough than the titanium.

Aluminum

It has the following special features:

i. Very economic
ii. Very much resistant to corrosion
iii. Extremely light weight
iv. Cosmetically attractive. It can be dyed in different attractive shades.
v. It can also be anodised, i.e. aluminum oxide forms the surface layer which is very hard. It is also possible to add decorative finish to the anodised metal.

Only disadvantage is that it may become very cold, being a good heat conductor, which may be overcomed by insulating it with plastic end covers. However, aluminum frames are rarely dispensed nowadays despite having special features as mentioned earlier. However, in future it may return as fashionable framewear due to it’s modern design look and cosmetic appeal.

Nickel Silver (or German Silver)

Nickel silver frames are usually marketed after being electroplated with pure nickel. It has following advantages as a frame material:

i. Corrosion resistance
ii. Cheaper than semiprecious metals.
iii. Easily adjustable.
iv. Convenient to work with

However, it is allergenic and may cause contact dermatitis in susceptible peoples.

METALLIC–SEMIPRECIOUS

Titanium

Titanium as spectacle frame material has some unique properties:

i. It is more flexible and durable than any other metal frame.
ii. It is ultra light. Pure titanium frames are 48% lighter than conventional metal frames, i.e. stainless steel.
iii. It is highly resistant to corrosion from perspiration.
iv. It is possible to add colourful “enamelling”, i.e. designs.
v. It is extremely heat resistant and comfortable to wear.
vi. It is nonallergenic.

However, it is quite expensive material. Hence, titanium frames are available in three different types utilising different proportion of the metal:

- Pure titanium
- “Clad” titanium—A surface layer of nickel envelops the core metal of pure titanium.
- “Partial” titanium—It is a frame formed by a combination of parts made up of pure titanium, clad titanium and other metals.

However, it is safer to avoid nickel alloy in titanium frames since it may cause contact dermatitis.

Titanium frames should be perfect fit during selection since it returns to it’s original shape after accidental bending due to it’s high memory property.

Memory Metal

Memory metal frames are able to hold onto their adjustments even after twisting or bending. It is produced by a special blending of titanium and nickel alloys. So, they are used in parts of the frame which are subject to stress, notably bridges and temples of the frame.

Gold Plated Materials

Gold plating is an electrolytic process by which a layer of gold of 18 ct is evenly deposited onto the surface of the base metal. The following base metals are used for gold plating:

i. Bronze
ii. Nickel silver and alloy of nickel silver
iii. Titanium.

Rolled Gold

Rolled Gold is a material which is produced by bending a bar of base metal to a gold alloy, which is further "rolled", i.e. compressed between rollers. This makes both the gold and the base metal harder and springier. Rolled gold spectacle frames are still available and occupy the upper end of the exclusive gold frame market.

METALLIC–PRECIOUS

Pure gold is very soft. So, it is alloyed with other metals to achieve necessary strength and hardness of a spectacle frame. Gold is very resistant to corrosion, very easily adjustable and convenient to work with. Fine gold is termed as 24 carat (ct). However, 9 carat (ct) gold is considered as the most ideal for gold spectacle frames.

PLASTIC

Before the advent of synthetic plastics, natural plastics were commonly used for making frames. These natural plastics include bone, ivory, animal horn, tortoise shell. As a material tortoise shell is unique due to it's durability, plastic bonding properties, attractive colour and mottled appearance. However, it has now become obsolete due to declaration of the hawksbill turtle, the source of tortoise shell as endangered species by WWF (World Wildlife Fund). Synthetic plastics are made from organic materials and are divided into two distinctive types:

Thermoplastic

On exposure to heat, they soften to allow reshaping without undergoing any fundamental change of the plastic property. They are also referred to as thermosoftening.

Thermosetting

They undergo irreversible loss of plastic property on polymerization. On exposure to certain degree of heat the material breaks up.

Spectacle frames are made from the raw material by several methods, e.g. compression moulding, injection moulding, casting etc. Varieties of plastics used as frames are:

a. *Cellulose nitrate:* It is the earliest cellulose plastics used in spectacle frame industry. It is commercially marketed first time by the Hyatt brothers of USA under the trade name *Celluloid*. It is obtained by nitration of cellulose, the main constituent of cell walls of plants. Short fibres left on the surface of the cottonseeds are the source of cellulose. Nitrocellulose thus produced is mixed with a plasticiser, ideally camphor, to manufacture blocks of cellulose nitrate through complex processes. Advantages of cellulose nitrate are:

i. It is strong and stable even in tropical and humid climates.
ii. It is convenient to work with.
iii. It's surface can be polished brightly.

The disadvantages of cellulose nitrate are:

i. It is very much inflammable.
ii. Therefore, it is banned in several countries as spectacle frame material.

b. *Cellulose Acetate (or Zylonite*): It is produced by acetylation of cellulose. The manufacturing process is essentially same as that of cellulose nitrate. Usually phthalate compounds are used as the plasticiser. It is the most commonly used material in plastic frame industry. Usually cellulose acetate is not affected by perspiration. Advantages of cellulose acetate are:

i. It is also very strong.
ii. It is much less inflammable.

iii. It is cosmetically attractive due to variations in natural look finishes.
iv. It is highly transparent.
v. It is convenient to work with.
vi. It is not allergenic.
vii. It is resistant to discolouration by perspiration.

Disadvantages of cellulose acetate are:

i. It absorbs moisture rapidly. Hence, it is not suitable for tropical and humid climates.
ii. It softens at relatively lower temperature (50°C). Hence, the frames are prone to damage by excess heat and sunlight.

c. *Acrylic resins:* The most common acrylic resin used in spectacle frame industry is polymethyl methacrylate (PMMA–Perspex). It has following distinctive features:

i. High level of transparency–It is attractive to the wearer cosmetically.
ii. Highly stable due to high softening point.
iii. However, it is not convenient to work with due to brittle nature of the material.
iv. It has low resistance to impact.
v. It is not inflammable. However, it is easily distorted by heat.

d. *Optyl:* It is an epoxy resin. It has following remarkable characteristics:

i. It is extremely resistant to heat–It can be heated to 200°C and it returns to it's original moulded shape on cooling in water.
ii. The material is hypoallergenic.
iii. It's plastic memory is high. Hence, it keeps it's shape alignment.
iv. It is extremely corrosion resistant, i.e. optyl is not affected by perspiration, cosmetics and sunlight. It retains appearance indefinitely.

e. *Nylon (or Polyamides):* The distinctive features are:

i. It is ultralightweight (30% of cellulose nitrate).
ii. It is not allergenic.
iii. It is durable.

iv. It is mainly used for spectacle frame of sunglasses, safety wear goggles, etc.
v. It is also nonadjustable due to high plastic memory. Hence, it is difficult to adjust by conventional methods.
vi. It is extremely heat resistant.

However, SPX, the superpolyamide overcame the disadvantages of nylon and replaced other materials as one of the major spectacle frame material. So, in addition to the advantages of nylon (ultralight, durable, hypoallergenic, heat resistant) it offers flexibility for adjustment.

f. *Carbon Fibre Graphite:* The special features are:
i. It is extremely durable and strong.
ii. It is lighter than aluminum.
iii. It is heat resistant.
iv. It is ultralight.

Development of synthetic plastic materials lead to substitution of precious metals and traditionally used natural materials like ivory, tortoise shell, and animal horn by the newer synthetic plastic materials. These materials are cheaper and in certain aspects superior to the earlier available materials. Cellulose acetate (zylonite) remained for long, as the most suitable frame material for the industry. However, epoxy resin (optyl) and later SPX (superpolyamides) and carbon fibre graphite material have broken the monopoly of cellulose acetate in the spectacle frame industry.

CHAPTER

12 Ophthalmic Lenses

INTRODUCTION

An ophthalmic lens is defined as a transparent optical system bounded by two polished surfaces, either plane or curved. Refractive errors are corrected by different types of ophthalmic lenses depending on the type of ametropia.

USES

- Correction of refractive errors
- Protection against harmful rays of electromagnetic spectrum
- Protection against external bodies.

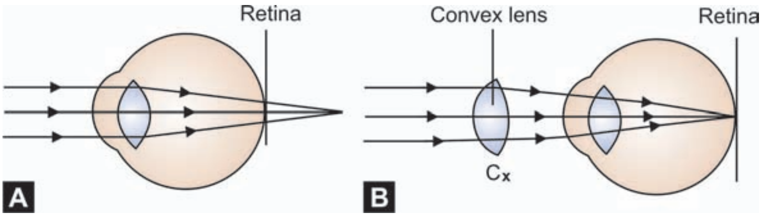
SPHERICAL LENSES

Spherical lenses correct refractive errors unaccompanied by astigmatism. A spherical lens is defined as a lens in which each surface forms a part of the surface of a sphere. However, a plane surface may be considered as part of a spherical surface of infinite radius. Power of spherical lens is expressed in diopter spherical (DSPH).

TYPES

Convex or Plus Lens

Convex lenses are worn by patients who are hypermetropic, i.e. farsighted. The image of an object falls behind the retina in hypermetropic people (Fig. 12-1A) and convex lens converges parallel rays of light to bring the image forward on the retina (Fig. 12-1B).



Figs 12-1:A and B: Use of convex lens for correction of hypermetropia (A) Hypermetropic eye and (B) Convex lens (C_x) Placed infront

How to identify convex lens?

- It magnifies images, i.e. makes them larger.
- When the lens is moved in front of the eye, the object moves in the opposite direction. This is called *against movement*.
- The lens is thicker in the middle and thinner on the edges.
- The greater the vertex distance (further away from the eye), the stronger the power, i.e. magnification of the lens.
- It is conventionally denoted by plus (+) sign in trial lenses.

Uses: It is used in the treatment of:

- Hypermetropia
- Presbyopia
- Aphakia
- In low visual aids as magnifier.

Types of convex lenses: The power of each surface of a lens add up to arrive at the power of the lens as a whole. So, the total power desired is distributed between the two surfaces. Convex lenses are usually available in following standard forms;

i. *Equiconvex:* Both surfaces have the same curvature, i.e. same plus (+) power (Fig. 12-2A). Nowadays, this spectacle lens form has become obsolete.

ii. *Planoconvex:* The surface facing the eye, i.e. back surface is plane and the front surface provides the necessary plus/ convex power (Fig. 12-2B).

iii. *Plus/Convex meniscus:* This is the usually available form of plus/minus spectacle lenses. Conventionally, the front surface is always convex and the back surface is always concave (Fig. 12-2C), in plus/minus meniscus lenses.

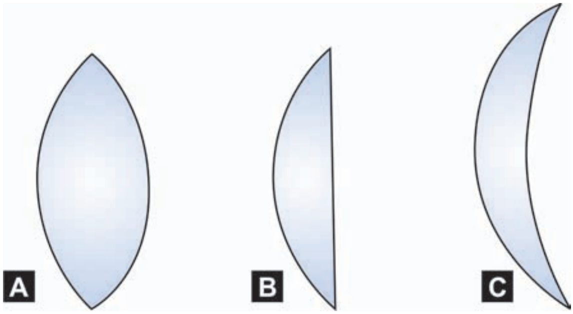
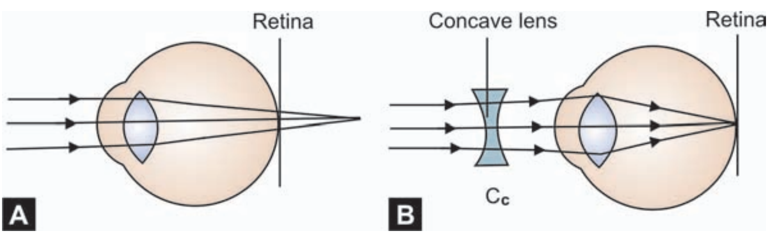


Fig. 12-2A to C: Different standard forms of convex spherical lenses (A) Equiconvex, (B) Planoconvex and (C) Plus meniscus

Concave or Minus Lens

Concave lenses are worn by patients who are myopic, i.e. nearsighted. In myopia, the image of an object falls in front of the retina (Fig. 12-3A) and concave lens diverges the parallel rays of light to shift the image behind, on the retina (Fig. 12-3B).



Figs 12-3A and B: Use of concave lens for correction of myopia (A) Myopic eye and (B) Concave lens (C_c) placed infront

How to identify concave lens ?

- It minifies images, i.e. makes them smaller.
- When the lens is moved in front of the eye, the objects move in the same direction. This is called *with movement*.
- The lens is thinner in the middle and thicker on the edges.
- The greater the vertex distance, the weaker the power of the lens.
- It is conventionally denoted by minus (–) sign in trial lenses.

Uses: It is used in the treatment of:

- Myopia
- Some optical diagnostic and laser lenses, e.g. Hruby lens (–58.60D), central concave lens of single/two/three mirror gonioscopic lenses (–64.00D).

Types of concave lenses: Like convex lenses, concave lenses are usually available in following standard forms;

i. *Equiconcave:* Both the surfaces are symmetrically concave (Fig. 12-4). Like equiconvex lens it is also obsolete.

ii. *Planoconcave:* The front surface is plane and the back surface, i.e. the surface facing the eye provides the necessary minus/ concave power (Fig. 12-4).

iii. *Minus meniscus:* Minus lenses are marketed in this standard form (Fig. 12-4).

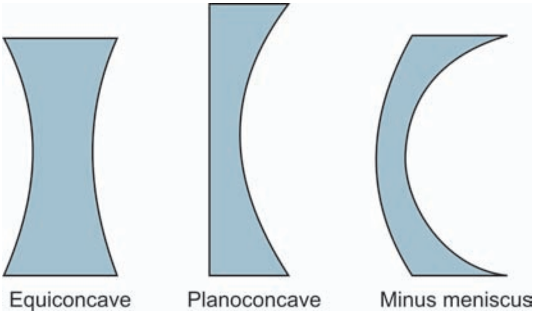


Fig. 12-4: Different standard forms of concave spherical lenses

CYLINDRICAL LENSES

Cylindrical lenses correct regular astigmatism. It is a segment of a cylinder of glass cut parallel to it's axis.

HOW TO IDENTIFY A CYLINDRICAL LENS ?

- Conventionally, cylindrical lens has one toric surface, i.e. a surface having meridians of least and greatest curvature aligned at right angles to each other.
- Conventionally, two marks are seen on the peripheral/outer part of the lens, which indicate the axis of the lens.

- When the lens is moved in the direction of the axis, there is no movement of the object. The meridian of the least power, i.e. curvature is the axis of the cylindrical lens.
- When the lens is moved in a direction at right angles to its axis, i.e. the meridian of greatest curvature, the movement of the object depends on the convexity/concavity of the cylindrical glass. In convex cylindrical lens the object moves in the opposite direction (against movement). In concave cylindrical lens the object moves in the same direction (with movement).
- Cylindrical power is expressed in diopter cylinder (DCYL). A plus (+) sign denotes convex cylindrical lens and a minus (–) sign denotes concave cylindrical lens in the trial lenses.

TYPES OF CYLINDRICAL LENSES

i. Planocylindrical lense—In planocylindrical lens, one meridian contains no power and is the axis of the lens. The toroidal meridian, i.e. the meridian of greatest curvature is located at right angle to the axis.

ii. Spherocylindrical lens—It contains spherical component throughout the lens.

UNIT OF LENS POWER

Diopter (abbreviation D) is the basic unit of power of a lens and is defined as the reciprocal of the focal length of the lens in metres. So,

$$\text{D (Diopters)} = \frac{1}{\text{Focal length}} \text{ (in metres)}$$

Example 1: If the focal length of a lens is 2 metres, find out the dioptric strength of the lens ?

Ans. 1/f (metres) = D, So, ½ = 0.50D

Example 2: If the focal length of a lens is 50 cm, find out the power of the lens ?

Ans. 1/f (metres) = D, So, 1/0.5m = 2.00D

Example 3: If the power of the lens is +4.00D, find out the focal length of the lens ?

Ans. D = 1/f (metres), So, f = 1/D, So, f = ¼ = 0.25 metres = 25 cm.

SPECIAL TYPES OF LENSES

TORIC LENS

Like meniscus lenses, toric lenses have one convex and one concave surface. However, in toric lenses only one surface remains spherical and the other surface contributing the astigmatic power is called toroidal surface. So, a toric lens can be imagined as a cylindrical lens superimposed upon a spherical lens (Fig. 12-5). A toric lens with a power of +3.00D in one principal meridian and +6.00D in other principal meridian can be considered as a +3.00DSPH lens with a +3.00DCYL lens superimposed upon it. This can be prescribed as +3.00DSPH with +3.00DCYL or +3.00DSPH/ +3.00DCYL. Thus a toric lens can also be expressed numerically as;

$$\frac{\text{Power of the Sphere}}{\text{Power of the Cylinder}}$$

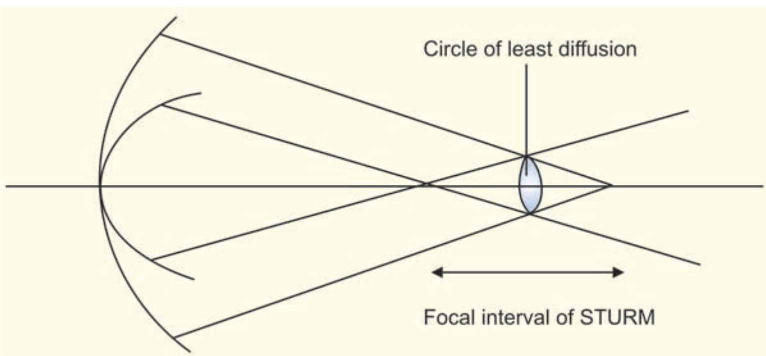


Fig. 12-5: Image formation by a toric lens

There are two optical ways to reduce weight and thickness of high powered lenses. They are:

- High index lens
- Lenticular lens.

HIGH INDEX LENS

Lenses with higher refractive indices between 1.64 and 1.73 are considered as high index. Lenses with refractive indices higher than 1.73 are termed as "very high index". High index lenses are available in both glass and resin lens variety.

Advantages of high index lens:

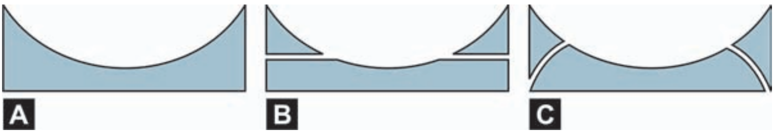
- Comfortable to wear and cosmetically superior
- Thickness of the lens is reduced
- Weight of the lens is either same or slightly less
- Particularly suitable for myopics due to reduction in edge substance.
- Disadvantages of high index lens:
- Increased transverse chromatic aberration due to lower constringence/Abbé's number (see chapter-11).
- Higher surface reflectance (see chapter–13)

LENTICULAR LENS

The idea of lenticular lens is to reduce the weight of the lens by decreasing the thickness of edge substance. In lenticular lens, the central area called "aperture", is responsible for the dioptric strength of the high-powered glass lens or resin lens. Other lenses, i.e. spherical lens, cylindrical lens, toric lens and aspheric lens fall within *full aperture* category. Lenticular lenses are of two types:

Minus/Concave Lenticular

Minus lenticular lens can be created in both planoconcave glass and resin lenses from normal blank (Fig. 12-6A) by the process of either surfacing or glazing (Figs 12.6B and C). Usually minus lenticular lens are available in single vision lenses. In multifocal lenticular lenses the carrier margin particularly in the lower part may interfere with vision.



Figs 12-6A to C: Transformation of planoconcave blank to minus lenticular lens (A) Planoconcave lens blank, (B) Minus lenticular with a plano carrier margin and (C) Minus lenticular with a convex carrier margin

Plus/Convex Lenticular

They are created from semi-finished form, moulded form, single piece resin (Fig. 12-7). They are available in either single vision or bifocal lens style. However, glass plus lenticular lenses are created by the process of surfacing. In plus/convex lenticular lens the process is based on reducing the centre substance.

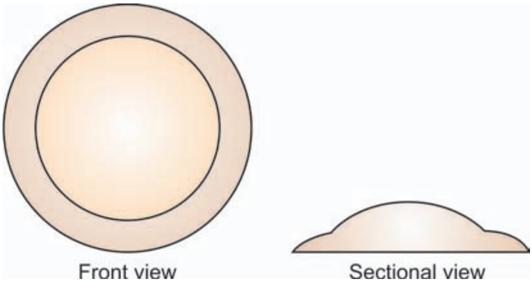


Fig. 12-7: Plus/Convex lenticular lens

ASPHERIC LENS

These lenses are nonspherical and have more than one curve on the front surface. The lens is designed in a fashion so that there is a series of different curves on the front that move from the centre towards the edge. This makes the lens flatter and thinner. They are designed to neutralise the following disadvantages of high powered convex (+) lenses:

i. Pincushion type of distortion—It occurs when a grid pattern is viewed through the lens (see Fig. 7-9 in chapter 7).
ii. Spherical aberration—It occurs because light rays passing through the periphery of a high power plus lens will come to a focus earlier, whereas the light rays passing through the centre of the lens will come to a sharp focus at the retina (see Fig. 7-7A in chapter 7).

So, aspheric (nonspherical) lenses are developed. An aspheric surface is spherical at the centre but becomes progressively less convex towards the periphery, e.g. a +10.00DSPH lens will be +10.00DSPH at the centre and gradually reducing to +6.00DSPH at the margin (Fig. 12-8). This aspheric surface design neutralises the pincushion distortion and peripheral blurring of images (spherical aberration). This results in a wider field of view with negligible peripheral distortion and prismatic effect.

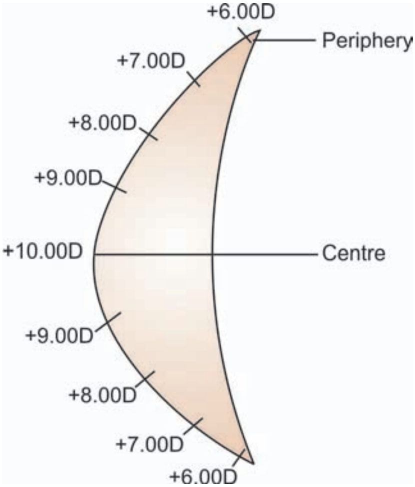


Fig. 12-8: Design of a +10.00DSPH aspherical lens

Aspherical lenses are available in glass, high index resin lens and resin lenses, usually in the dioptric range of +6.00DSPH to–15.00DSPH. Aspheric lenses are available in single vision, bifocal and progressive addition lenses.

BALANCE LENS

These lenses are fitted to a spectacle frame to balance the weight of the other lens, where the patient's vision cannot be improved. The balance lens power and style should match the other lens for improved cosmetic appearance.

TRANSPOSITION

Transposition is the term applied to the method of converting a prescription of lens power to another possible optically equivalent lens power. Thus, by transposition a prescription of convex cylindrical lens can be converted to optically equivalent concave cylindrical power, or *vice versa*.

RULES OF TRANSPOSITION

i. **Power of the spherical lens**–Add the spherical and cylindrical power algebraically, taking into account their signs.

ii. **Power of the cylindrical lens**–Only change the sign of the cylinder from plus (+) to minus (–), or *vice versa*. The numerical strength of the cylinder remains the same.

iii. **Axis of the cylinder**–Change the axis by 90º. If the original axis is at or less than 90°, add 90° to it. If the original axis is over 90°, subtract 90° from it.

EXAMPLES

1. If the original prescription is –3.00DSPH with +1.00DCYL 90°↓

   Rule i. –3.00 + (+) 1.00 = –2.00 DSPH

   Rule ii. +1.00DCYL becomes –1.00DCYL

   Rule iii. 90°↓ axis becomes 180° axis →

   Hence, the transposed power is –2.00DSPH with –1.00DCYL 180° →

2. If the original prescription is –3.00DSPH with -1.00DCYL 45°↙

   Rule i. –3.00 + (–) 1.00 = –4.00 DSPH

   Rule ii. –1.00DCYL becomes +1.00DCYL

   Rule iii. 45°↙ axis becomes 45° + 90° = 135°↘ axis

   Hence, the transposed power is –4.00DSPH with +100DCYL 135°↘ axis.

3. If the original prescription is –2.00DSPH with +2.00DCYL 105°↘

   Rule i. –2.00 + (+) 2.00 = 0, i.e. Plano

   Rule ii. +2.00DCYL becomes –2.00DCYL

   Rule iii. 105°↘ axis becomes 105º–90º = 15° axis ←

   Hence, the transposed power is –2.00DCYL 15° axis ←

NEUTRALISATION (DETERMINATION OF POWER OF A LENS)

Neutralisation is the technique for determining the power of an ophthalmic lens. Neutralisation is done by following methods.

MANUAL METHOD

It is basically a very simple but quick and accurate way of checking the power of glasses. It is done by trial and error with the help of the lenses present in the trial box. In this method, lenses of known power are placed in contact with the lens under verification until the power of the combination becomes zero, i.e. there is no movement of the distant object. A lens under verification will be neutralised by another lens of equivalent power of opposite sign. So, a –3.00DSPH lens will be neutralised by a +3.00DSPH lens {–3.00DSPH + (+3.00DSPH) = 0}.

Neutralisation is based on the identification properties of convex and concave spherical lenses discussed earlier in this chapter. Convex spherical lens exhibit against movement and concave spherical lens exhibit with movement of the object, if they are moved in front of the eye.

RULES OF NEUTRALISATION

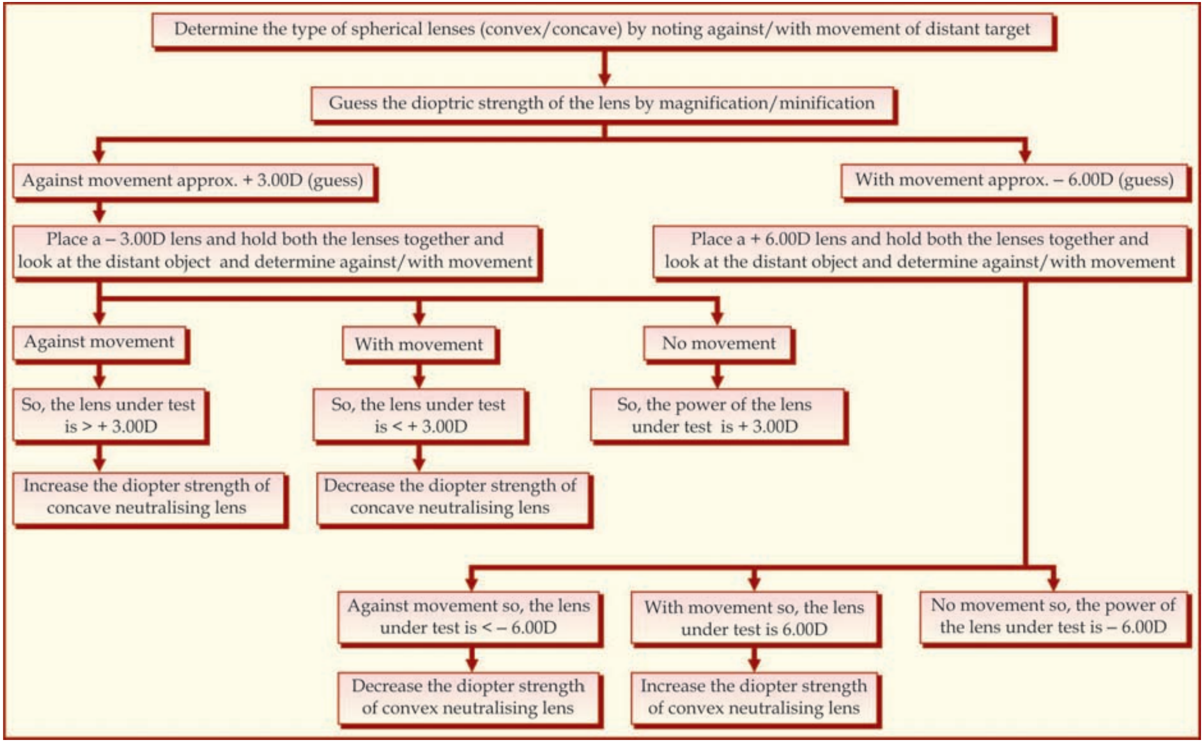
- Object/Target should be placed at a convenient furthest distance.
- Ideally a cross with two limbs at 90° should be the target. In the absence of cross, a window frame or other vertical and horizontal intersection may be employed as the target. Conveniently, Snellen's distant vision chart may also be used.
- Neutralising lens should be placed in close contact with the front surface of the spectacle lens.
- Attention must be paid to the central portion of the cross during neutralisation.
- The lenses should be held in front of the eyes.

PROCEDURE OF NEUTRALISATION

Manual

a. Spherical lenses (Table 21.1)
b. Astigmatic lenses–Here the same principle is applied but it requires further steps. It can be done in two ways—
   1st procedure–Here both spherical and planocylindrical neutralising lenses are employed.

Table 12-1: Manual neutralisation of spherical lens

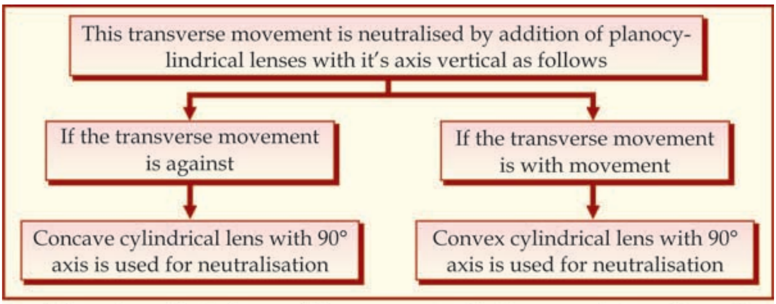


i. Align the principle meridians of the lens under test with the cross by rotating until no scissors effect is seen. So, the principle meridians are now vertical and horizontal.

ii. Neutralise the vertical meridian with a spherical lens as described earlier.

iii. Now, the transverse movement in horizontal meridian still exists contributed by the cylindrical power of the lens under test.

iv.



2nd Procedure – Both the meridians are neutralised separately by using only spherical neutralising lenses. i., ii, and iii. are similar to the 1st procedure. iv. The horizontal meridian is now neutralised in a similar way independently

Example: If vertical meridian is neutralized by a +2.50D lens and the horizontal meridian is neutralised by a –3.00D lens what will be the power of the lens ?

Ans. Hence, the power of the vertical meridian will be –2.50D and power of the horizontal meridian will be +3.00D. So, the power of the lens under test will be either –2.50DSPH with +5.50DCYL 90° or +3.00DSPH with –5.50DCYL 180°.

Mechanical

It can be done by the following instruments (discussed in chapter 16).

- Geneva lens measure
- Focimeter/Lensometer
- Automated Lensometer.

CHAPTER

13 Coatings and Tints of Lenses

ANTIREFLECTION COATING (AR COATING)

It is a coating applied to the lens that eliminates or reduces reflections on the front and back surface of the lens and sharpens wearer's vision. There are following types of reflection which may cause visual disturbance to a person wearing spectacles;

a. **Frontal reflections**–The light incident on the front surface of the lens is reflected back to the person in front of the spectacle wearer. This is disturbing to the viewer since there is an inability to see the eyes of the person spoken to (a in Fig. 13.1).

b. **Backward reflections**–The light is incident on the back surface of the lens from behind the wearer. This light is reflected into the wearer's eye causing visual trouble specially at dusk, in poor light and during driving at night (b in Fig. 13-1).

c. **Internal reflections**–There is also some internal reflection between the two surfaces of the lens which varies with the power and position of the lens (c in Fig. 13-1).

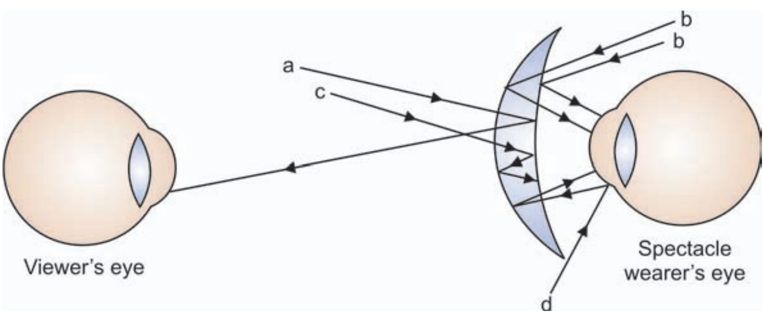


Fig. 13-1: Sources of various types of reflections
a = Frontal; **b** = Backward; **c** = Internal and **d** = Corneal

d. **Corneal reflections**–Light incident on the cornea of the wearer may be reflected back on to the lens surface causing further visual disturbance, i.e. visual annoyance (d in Fig. 13-1).

Fresnel's formula is used to determine the proportion of light lost by reflection at the interface between two transparent media.

$$\text{The reflection } p = \left[\frac{n_2 - n_1}{n_2 + n_1}\right]^2$$

Where n_1 = refractive index of the first medium

n_2 = refractive index of the second medium

So, for a lens (R.I. = n) in air (n = 1) the percentage of light reflected (surface reflectance) is deduced by

$$p = \left[\frac{n - 1}{n + 1}\right]^2 \times 100\%$$

Example: 1. percentage of surface reflectance of crown glass (n = 1.523) (See Table 13-1)

$$p = \left[\frac{1.523 - 1}{1.523 + 1}\right]^2 \times 100\% = 4.30 \ (4.297)$$

So, the percentage of surface reflectance from the two surfaces of a crown glass will be 4.30 × 2 = 8.60.

Example: 2. percentage of surface reflectance of CR–39 (n = 1.498)

$$p = \left[\frac{1.498 - 1}{1.498 + 1}\right]^2 \times 100\% = 3.97 \text{ (Fig. 13-2)}$$

So, the percentage of surface reflectance from the two surfaces of a resin lens (CR–39) will be 3.97 × 2 = 7.94.

Surface reflectance is reduced by applying a thin film of transparent material thickness of which is 1/4th of the wavelength of the incident light and of lower refractive index than that of the lens, on both the surfaces. Now, there exists two sources of reflections from the exposed surface of the coating film and the surface of the lens. However, their combined effect gives rise to less reflection since light reflected from the superficial surface of A.R. coating layer and light reflected from the superficial surface of the

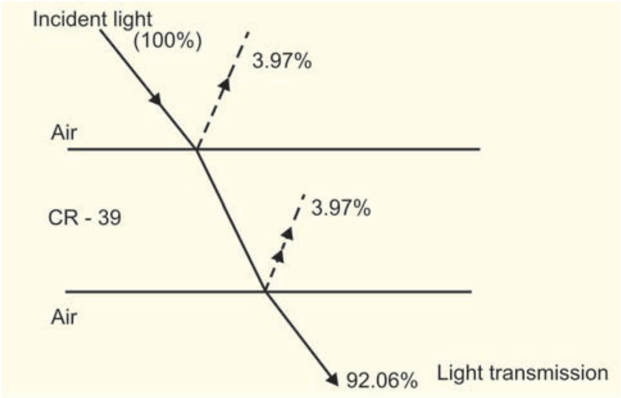


Fig. 13-2: Reflection and refraction of light through CR–39 lens

Table 13-1: RI, V-value, Surface Reflectance at each surface and both surfaces of different lens materials

Material	*RI*	*V–Value*	*Surface reflectance at each surface*	*Surface reflectance from both surfaces*
Crown Glass	1.523	59	4.30	8.60
Resin Lens	1.498	57.8	3.97	7.94
Polycarbonate	1.586	30	5.13	10.26
High Index Glass	1.80	25.4	8.16	16.32
Trivex	1.53	44	4.40	8.80

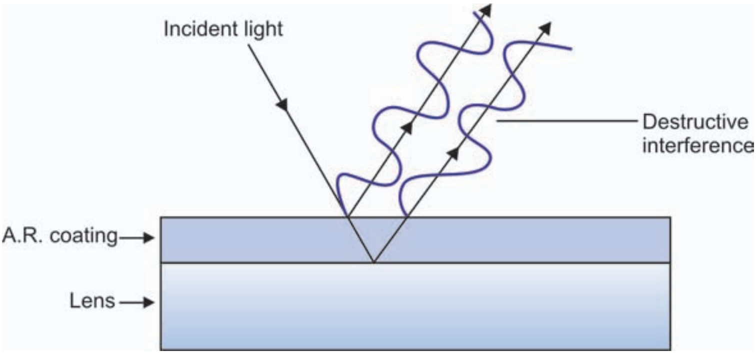


Fig.13-3: Destructive interference in antireflection coating

lens eliminate each other by destructive interference to reduce reflection (Fig. 13-3).

AR COATING OF CROWN GLASS

Crown glass (RI = n = 1.523) is coated with magnesium fluoride (RI = n = 1.38) which increases transmission of light, i.e. reduces surface reflection. However, the appropriate coating material for crown glass should have refractive index of 1.234 to fully eliminate surface reflectance.

A.R. COATING OF RESIN LENS

Technical difficulties of application of coating material on surface of resin lens and the absence of suitable coating material of lower refractive index lead to the development of double layer of A.R. coating of resin lens. Now, multilayer coatings are also developed to eliminate surface reflections almost totally from the visible light spectrum. A special type of multilayer coating, termed "broadband" is developed, which is far superior than usual multilayer coating. *A.R. coating allows more light to pass through the lens and enter the eye, whereas tinting decreases light transmission through the lens*. Light transmission through uncoated resin lens is = 100–7.94 = 92.06% (Fig. 13-2), whereas light transmission through double layer A.R. coating is 96%. Multilayer coating (broadband) allows light transmission of more than 99%.

A.R. coatings also absorb a good amount of UV rays. However, it is not as effective as the UV coating. A.R. coating is recommended specially in following situations;

- Night driving–At night the driver's judgement is adversely affected particularly from oncoming headlight beam reflections. A.R. coating makes it safer by eliminating the reflections.
- Computer work
- Higher refractive errors
- In patients wearing polycarbonate lenses, A.R. coating allows more light to pass through the dense polycarbonate lenses.

TINTS

Tinting of spectacle lens is incorporation of colour to deliberately decrease transmission of light through it. They are usually used to protect the eyes from unwanted glare or bright sunlight. However, it may also be used for cosmetic purpose.

Many different shades and colours are available for this purpose. The shades are usually labeled either by numbers or percentages. The percentage indicates the percentage of light transmission blocked. For example, lenses of crown glass transmit 91.4% of visible spectrum of light (8.60% loss is due to surface reflections). An addition of tint of 10% will practically allow light transmission of 81.40%. *Therefore, patients wearing very high percentage of tinted spectacle are advised against driving at night*.

Lens tinting is done by following methods:

i. Surface coating—A deposit material is coated on the back surface of the lens to exaggerate surface reflection. Glass lenses are usually tinted in this process.

ii. Dye tinting—Resin lenses are usually dye tinted. They are tinted by placing in a dye chamber bath. The dye penetrates the lens material. Polycarbonate is very resistant to tinting. However, the hardcoat over the polycarbonate takes up the tint. Tint can be applied over the whole lens (solid tint) or the tint can be applied in a gradient manner (*gradient tint*). In gradient tint, the tint is darker on the top and gradually fades to clear at the bottom.

IMPORTANT FACTS REGARDING TINT

- Tint on glass lens is permanent.
- Tints do not change from light to dark when going from indoor to outdoor.
- Tint on resin lenses can be darkened or lightened. However, darkening of tint on old resin lenses tend to show the scratches prominent.
- Tint on polycarbonate lenses can also be lightened or darkened. However, it may ruin the colour or damage the lenses.

- Tint accentuates reflection and therefore, diminishes vision.
- Colour tint in a plane glass is uniform, where centre and edge thickness are equal. However, in a convex glass the thicker central area has a deeper colour. Conversely, in a concave lens the central area which is thinner, has a lighter shade.
- The larger the lens, the more pronounced is the colour shade variations.
- If the refractive correction is more than ±4.00D or the refractive error between the two eyes is quite significant, special care has to be taken to achieve uniform colour tint. Resin lens is dye tinted and glass lens is surface tinted for uniform colour coating.
- Mirror coating—Silver or chromium coating may be applied on the lenses by the process of surface coating to design mirrored lenses to create mirror effect. It allows the wearer to see through the lens, but the observer/passerby cannot see through it.
- Colour tints are usually applied before antireflection coatings where both tint and A.R. coating are applied to the lens.
- Colour tints which affect traffic signal colours (red, green and yellow) interpretation should not be used.
- Colour tinted lenses to be cleaned frequently since they attract dust and debris on the lens surface.

PHOTOCHROMISM

Photochromic lens is a lens which darkens on exposure to ultraviolet rays (sunlight) and lightens again on removal from the sunlight i.e., the lens changes colour according to lighting conditions. Glass photochromic lens (developed by Corning Inc.) contains trapped microscopic tightly packed clear *silver halide crystals*. On exposure to sunlight, these silver halide crystals dissociate into free silver. These free silver particles form cluster of silver colloids, which absorb UV radiation, to cause darkening of lens. When the wearer returns indoor, silver halide crystals are reconverted by recombination of free silver particles with the trapped halides. Thus the lens becomes clear again.

Photochromic lenses must always be replaced in pairs. This is because the reaction of photochromic lenses increase directly in proportion to the numbers of light/dark cycles they have undergone. Thus, an older lens will react much better than a new lens which requires a running time, i.e. several light/dark cycles of activation period before it achieves full reaction or activation. All photochromatic lenses possess additional quality of good UV radiation absorber. The darkening process is more rapid than the lightening process.

PHOTOCHROMISM OF GLASS LENSES

Glass Photochromatic lenses are available in two basic colour choice, gray or brown. In glass lenses, the silver halide crystals are trapped within the glass. So the light/dark cycles continue indefinitely. They are temperature dependent, i.e. darkens more easily in cold climate and lightens easily in hot summer.

PHOTOCHROMISM OF RESIN LENSES

The technology of photochromism in resin lenses is different and complex and is developed by the Transition Optical Inc.

Therefore, resin photochromatic lenses are conventionally termed as Transition lenses. These resin lenses are moulded from CR-307 monomer, which is subsequently treated with imbibing process. Millions of photosensitive molecules *(Indolino Spironapthoxzine)* are uniformly distributed within the front surface of the lens upto the depth of 100-150 µm. Resin photochromatic lenses degrade gradually due to fatiguability of the coating material from exposure to UV radiation over a period of time. Resin photochromatic lenses are also temperature sensitive. This lens gets darker in cold temperatures (winter) than hot summer. Technically superior photochromatic resin lenses (Sunsensor) developed by Corning Inc. contain photosensitive material within the substance of the resin lens (like glass photochromatic lenses). So, it imparts much longer light/dark cycles like glass photochromatics.

Effect of AR Coating on Photochromatic Resin Lenses

- A.R. coating reduces incident light reflectance, i.e. increases transmission of light.

- AR coating absorbs a good amount of UV light. So, the photochromic activation property will be reduced by approximately 15%. Hence, the A.R. coated photochromatic lenses will be less darker on exposure to UV light than only photochromatic lenses.

IMPORTANT FACTS OF PHOTOCHROMATIC LENSES

- Photochromic lenses darken only on exposure to UV rays. Hence, they may darken even inside a room on exposure to UV lights. The darkening performance may be poor on a foggy day.
- To obtain their optimum potential, photochromatic glasses need to be exposed to at least 10 light/dark cycles. If they are not worn for a longer period the light/dark reactivation cycles need to be repeated.
- Colour change in photochromatic lenses are also temperature dependent. So, they gets darker in winter than hot summer.
- Photochromatic glasses are thicker than untreated glasses. The darkening effect is directly proportional to the thickness of the photochromatic lenses for a given UV rays exposure.
- Photochromatic lenses are designed to absorb only UV rays. Hence, infrared rays (IR) continue to be transmitted through these lenses.

HARD COATING/SCRATCH RESISTANT COATING

Advent and availability of superior quality scratch resistant coatings eliminated the sole and main disadvantages of CR–39 and polycarbonate lenses. It is a very thin clear layer of coat applied to the lenses particularly resin lenses and polycarbonate lenses to protect them from minor scratches that occur in everyday wear. They also protect the antireflection and colour tints. However, they cannot protect from scratches from sharp and hard impact. Optical effect of hard coating is insignificant because the difference in refractive indices of the coating material and the lens is negligible.

IMPORTANT FACTS REGARDING HARDCOAT

- The hard coating of resin lens is applied on the outer surface only by some lens manufacturer and on both surfaces by others. However, all polycarbonate lenses possess scratch resistant coating on both surfaces.
- These hard coatings are usually very long lasting.
- Bleaching of tint or colour change in a resin lens without hard coating is a simple process. However, it is not possible if the resin lens is already having hardcoating.
- Scratch resistant coatings additionally increase antireflection properties and incident light transmission. 92.06% light transmission by uncoated resin lens increases to 96% after addition of hardcoating.

ULTRAVIOLET INHIBITORS

All persons who are exposed to sun for longer period should wear UV protective lenses, since the ozone layer which is responsible for earth's protection against UV radiational effect is being continuously depleting. An ideal UV protective lens should absorb close to 100% of UV rays. The ozone layer in the earth's atmosphere absorbs UVC (200–280 nm) from sunlight (Fig. 13-4). Crown glass absorbs UV radiation upto 300 nm and resin lens absorbs UV radiation upto 350 nm (Fig. 13-4). The harmful effect of UV radiation on eyes can still occur upto 380 nm radiations. Polycarbonate lenses even when uncoated absorb all harmful radiations of UV rays. UV inhibitor coating applied on resin lens can block UV radiation upto 400 nm. UV radiation causes pterygium, pinguecula, snow blindness, cancers of the eye and ocular adnexa. UV coating imparts a very light yellow tinge/hue to the lens.

Infrared rays of wavelengths between 700–1400 nm (IR-A) are partly transmitted to retina and filters to these rays are usually incorporated in protective goggles.

WATER RESISTANT/HYDROPHOBIC COATING

Hydrophobic coating is applied over lenses for ease of cleaning. Antireflection coating treated Lenses, tend to show smudges and

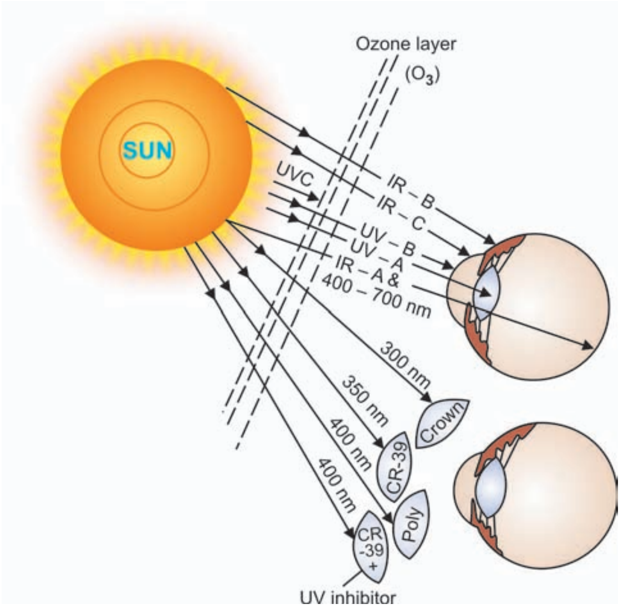


Fig. 13-4: IR rays and UV rays wavelengths and their absorption by ozone layer, cornea, lens, different lens material and UV inhibitor coating. UV-A = 315–400 nm, UV-B = 280–315 nm, UV-C = 200–280 nm, IR-A = 700–1400 nm, IR-B = 1400–3000 nm and IR-C = 3000–10^4 nm

marks more apparent due to the soft nature of the coating. To reduce this, lenses may be coated with hydrophobic coating. These coatings are even thinner than A.R. coating. They make the surface-wetting angle very low. In simple terms, they reduce adhesion of water or oil droplets and allow them to run off easily. It is applied over the A.R. coated lenses and increases hardness also. Hydrophobic coating is essentially a special layer of silicon deposit.

POLAROID LENSES

Polaroid lenses are meant to eliminate glare, reflected from flat surfaces such as water, snow, highways, etc. at certain angles. The polarising materials consist of nitrocellulose packed with ultramicroscopic crystals of herapathite. Their optic axes are aligned parallel to one another. Only 37% of incident light is transmitted through polaroid lens. Polaroid lenses are available in glass, resin and polycarbonate lenses.

FUNCTIONS OF POLAROID LENS

- Protection of eyes from direct and reflected UV rays.
- Improved visibility due to reduced glare from flat surfaces.

LENS CARE AND CLEANING

- Lenses should be cleaned by holding them under running water, preferably warm to wash away dust and debris, which may act as an abrasive. The lens is dried by wiping with a soft cloth or tissue paper.
- Since the lenses are susceptible to scratching on hard surfaces, patients must be cautioned against placing them with the lenses in contact with very hard surface.
- Resin lenses and polycarbonate lenses must be kept in cases which have a soft inner lining to avoid damage to the lens surfaces.

CHAPTER

14 Frames and Lenses: Dimensions, Measurements and Styles

SPECTACLE FRAME DIMENSIONS

The international method of spectacle frame dimension is known as "Box system". Earlier "Datum system" was practised. Basic frame dimensions in the "Box system" are:

1. Horizontal centre line—It is a line passing through the geometrical centres of the rectangular boxes that enclose the two lenses (1 in Fig. 14-1).
2. Vertical centre line—It is the line passing vertically through the centres of the rectangular boxes which enclose the two lenses (2 in Fig. 14-1).
3. Boxed centre—It is the point of intersection of the horizontal and vertical centre line (3 in Fig. 14-1).
4. Horizontal lens size—It is the distance between the vertical sides of the rectangular box that encompasses the lens (4 in Fig. 14-1).
5. Vertical lens size—It is the distance between the horizontal sides of the rectangular box that encompasses the lens (5 in Fig. 14-1).
6. Boxed lens size—The horizontal and vertical lens sizes of the box that encompasses the lens constitute the boxed lens size (boxed lens size = 4 × 5 in Fig. 14-1).
7. Distance between the lenses (DBL) measurement—It is also called bridge size. It is measured from the inside nasal point of one to the inside nasal point of the other (6 in Fig. 14-1).
8. Distance between the rims/eyewires (DBR) measurement—It is the distance between the rims at a certain specified level (a) below middle of the lower margin of the bridge (7 in Fig. 14-1).

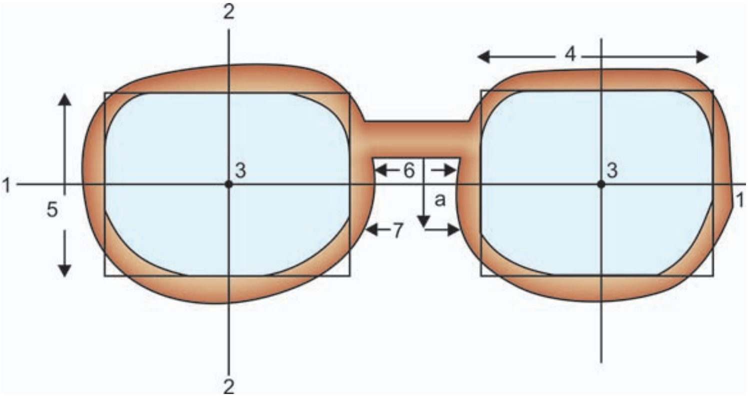
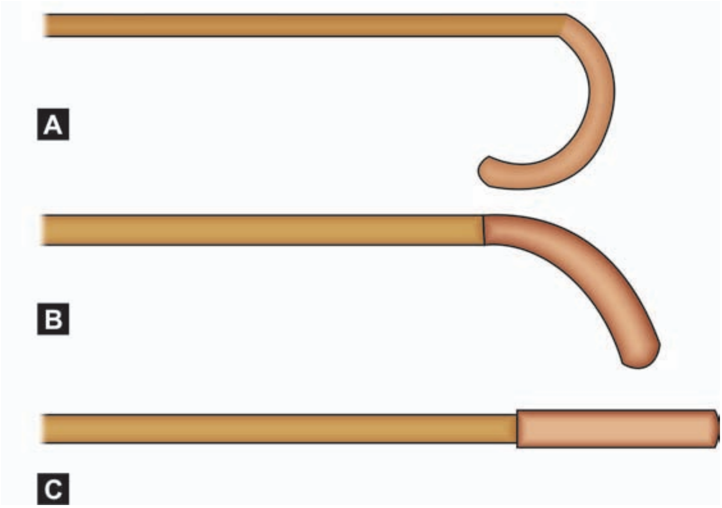


Fig. 14-1: Box systems–different frame dimensions. 1 = Horizontal centre line, 2 = Vertical centre line, 3 = Boxed centre, 4 = Horizontal lens size, 5 = Vertical lens size, 6 = DBL/bridge size and 7 = DBR

PARTS OF A FRAME

1. Eyewire/Rim/Frame front—It is the part of the frame which holds the lenses.
2. Temple—Temple is the long handle of the frame that hooks around the ear for support. It is of the following basic shapes:
   - Curl sides/cable (Fig. 14-2A)
   - Drop end sides/Standard (Fig. 14-2B)
   - Straight side/Library (Fig. 14-2C)
3. Temple tip—It is the plastic end piece on the temple for protection of the ear and skin.
4. Bridge—It is the part in the middle of the frame joining the two eyewires.
5. Nose pads—These are synthetic pads which rest directly on the nose for support. They either screw onto or snap into metal pieces.
6. Hinges—It join the temples with the eyewires.



Figs 14-2A to C: (A) Curl sides/cable, (B) Drop end sides/Standard and (C) Straight side/Library

COMMON TERMINOLOGIES ASSOCIATED WITH FRAME

Temple length—It is the length of the temple in millimetres (mm).
Mount—To fix the lenses in the eyewires.
Dismount—To take the lenses out of the eyewires
Dowel Point—It is the point where the hinge is located for connecting the temple with the eyewire.

SHAPES OF FRAMES

Usually following basic shapes are available for frame (Fig. 14-3):

1. Oval/Elliptical
2. Square
3. Round
4. Octagon
5. Aviator/Pilot–It is triangular in shape with a lower nasal cut away and lower temporal extension outwards.
6. Cat eye

7. Pantoscopic round oval (PRO)–It consists of a lower half circle and an upper half of ellipse.

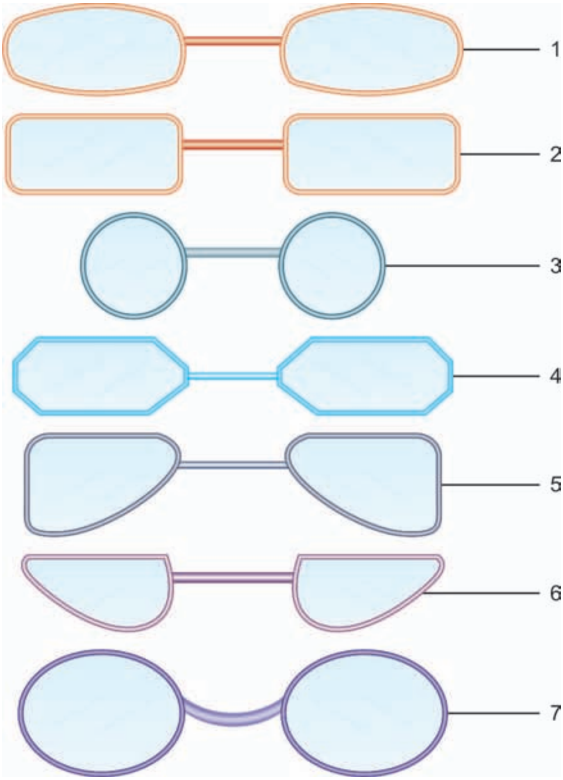


Fig. 14-3: Shape of frames. 1= Oval/Elliptical, 2= Square, 3= Round, 4= Octagon, 5= Aviator/Pilot, 6= Cat eye and 7= Pantoscopic round oval (PRO)

COMMON TYPES OF FRAMES

1. Full rim–The metallic or synthetic plastics hold the lens on all sides.
2. Semi rimless/Supra–Here the lens is surrounded by the frame material in the upper half and by a thin nylon thread in the lower half. The lenses are held in position not by screws, but by the thin nylon cord which is attached to the rims. The nylon cord passes through a groove on the edge of the lens.

3. True rimless/Drill mount–Here the lenses are held in position by screws to the bridge and the temples. The true rimless frames are essentially consist of three pieces, two temples and a bridge. The lenses are mounted at four points, two temporal and two nasal by screws.

SPECIAL TYPES OF SPECTACLE FRAMES

I. *Rarer/Antique Variety*
- Lorgon (or Quizzer)–It contains only one lens with a handle to hold the lens before the eye.
- Lorgnette–It contains two lenses mounted on a handle into which the lenses may fold (when not in use).
- Monocle–It is a single lens with or without a frame which is worn by holding it between the brow and the cheek.

II. *Medical Variety*
- Ptosis spectacles
- Hearing aid spectacles
- Low visual aid spectacles
- Welding spectacles.

III. *Sports Variety*
- Swimming goggles
- Squash goggles
- Ski goggles
- Snooker spectacles
- Divers spectacles.

IV. *Half Eyes*–They are usually worn for near vision, so that the person can look over the top of the frame for distant vision. Here the lenses cover only the lower half of the field of vision.

INFORMATIONS AVAILABLE FROM THE FRAME

Usually following information are obtained from the frame (Fig. 14-4):

- Temple length–Temple length is usually inscribed on the inner surface of the temple in millimetres (135 mm and 138 mm in Fig. 14-4).

- DBL (Distance between the lenses)–DBL/Bridge size is usually inscribed on the inner surface of the temple in millimetres (18 mm and 20 mm in Fig. 14-4).
- Horizontal boxed lens size–Size of the frame is usually inscribed on the inner surface of the temple in millimetres (52 mm and 50 mm in Fig. 14-4).
- Model No., name of the manufacturer and colour code of the frame are also usually inscribed on the inner surface of the temple (Fig. 14-4).

The DBL/bridge size usually ranges from 18 to 20 mm in Indian adult people, whereas in Chinese people it is usually 22 mm. In European people it is usually 16 mm. The horizontal boxed lens size is usually available in the order of 46, 48, 50, 52, 54 and 56 (millimetre).

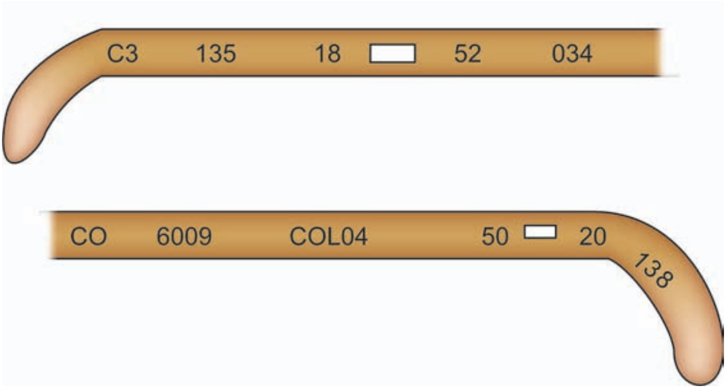


Fig. 14-4: Inner surface of temples with information inscribed

034	= Model No.=	C06009
C3	= Colour of Frame =	COL04
52	= Horizontal Boxed Lens Size (in mm) =	50
	▭ = Symbol of box system	
18	= Bridge size/DBL (in mm) =	20
135	= Temple length (in mm) =	138

LENS STYLES

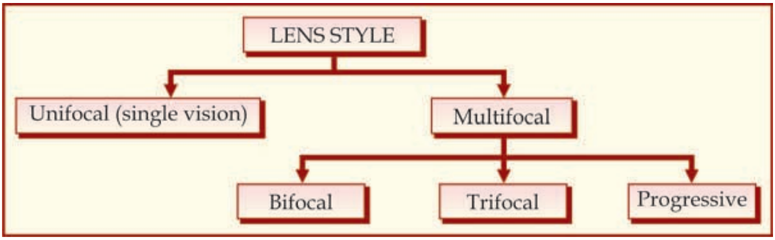


Fig. 14-5: Classification of lens styles

UNIFOCAL (OR SINGLE VISION) LENS

This is a lens with single dioptric prescription for either distance or near vision (Fig. 14-5).

MULTIFOCAL LENS

This is a lens with more than one prescription of dioptric strength (Fig. 14-5).

Bifocal Lens

This is a lens with two prescriptions for distance and near vision. Usually the upper segment is larger and is used for distant vision while the lower segment is smaller and is used for near vision. Types of bifocal lenses are:

Depending on shape

- Executive (E)/Franklin style bifocal–It is thicker than other types (Fig. 14-6A).
- D-bifocal/Flat-top bifocal (Fig. 14-6B).
- Kryptok/Curved bifocal (Fig. 14-6C).
- Round bifocal (Fig. 14-6D).
- Pantoscopic (P)/Pantobifocal (Fig. 14-6E).
- B bifocal (Fig. 14-6F).

Depending on manufacturing technique

- Split bifocal (or two piece bifocal)–Here two separate glass segments are held together in a frame (Fig. 14-7). It is the original type of bifocal invented by Benjamin Franklin. It is obsolete now.

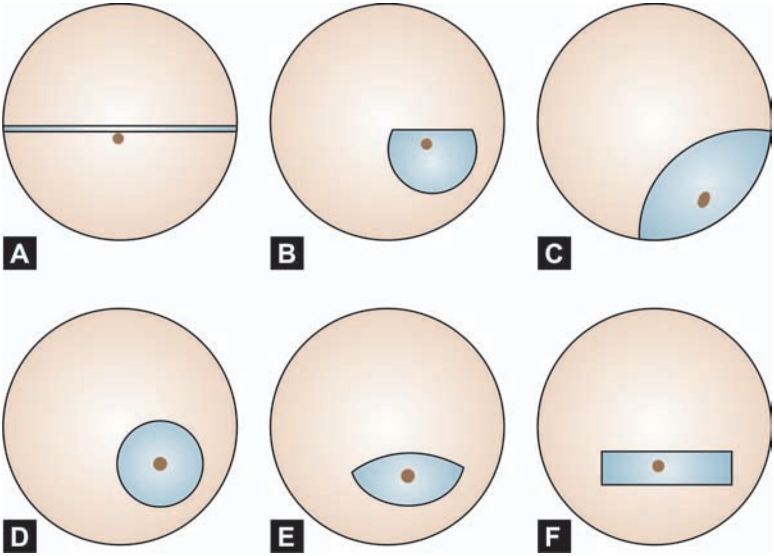


Fig. 14-6: Types of bifocals (depending on shape)
Dot (•) indicates optical centres of the near segment

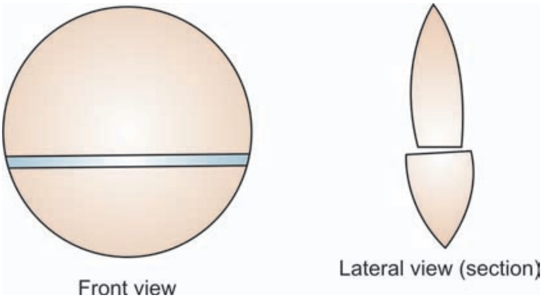


Fig. 14-7: Split bifocal

- Cemented bifocal–Here a glass button of higher refractive index is placed within the lens which has been split aned cemented. It is basically a three piece bifocal (Fig. 14-8). It is termed "Kryptok" (Greek meaning–hidden) by its inventor John Borsch Sr. This variety of cemented bifocal is also obsolete of now (Fig. 14-9).

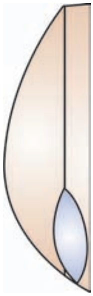


Fig. 14-8: Cemented bifocal (view on section)

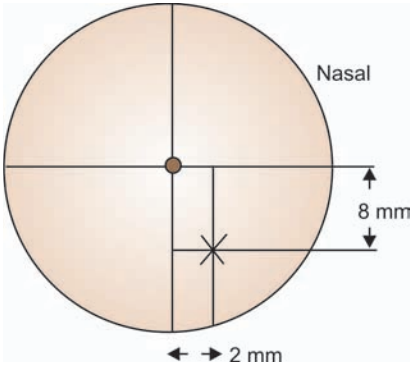


Fig. 14-9: Kryplok bifocal lens–Optical centres for distance and near. Near vision centre is 2 mm nasal to and 8 mm below the distance vision center. Distance vision centre = • , Near vision centre = X

- Fused bifocal–Here a button of a glass of higher refractive index imparting higher power for near vision is fused on to the surface of the crown glass (Fig. 14-10). This is the most commonly used variety.
- Solid bifocal (or one piece)–Here the near segment is made by grinding different curvature on one surface imparting higher power. So, solid bifocal glass/resin lens carries two distinct curvatures (Fig. 14-11). They are made from a single piece of material, i.e. either crown glass or resin lens. The lens in which the dividing line of a solid bifocal is made to disappear is called seamless (or blended) solid bifocal. In seamless solid bifocals the two curvatures are joined by a gradual transition zone.

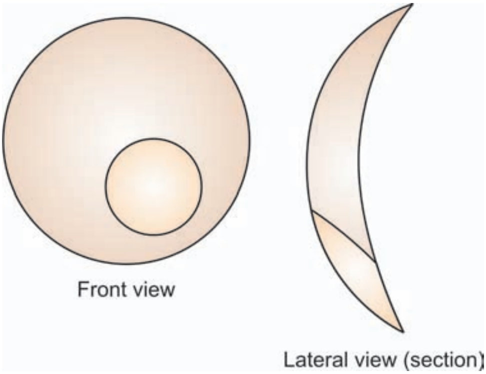


Fig. 14-10: Fused bifocal

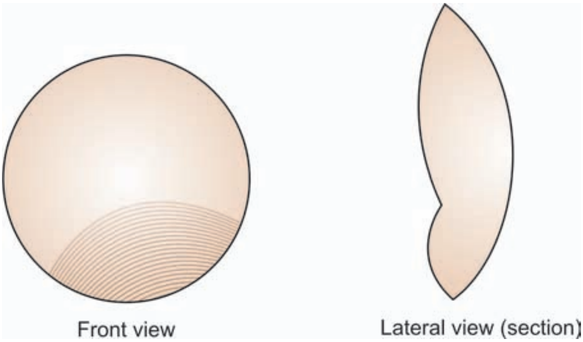


Fig. 14-11: Solid bifocal

Trifocal Lens

This is the lens with three prescriptions of power for distance, intermediate and near vision (Fig. 14-12). The strength of the intermediate addition is usually half of the addition prescribed for near vision. Trifocal lenses are usually of fused (glass)/solid (resin lens) variety. The depth of the intermediate segment usually ranges between 6 to 8 mm. The advent and advantage of progressive addition lenses are gradually declining the market share of trifocals.

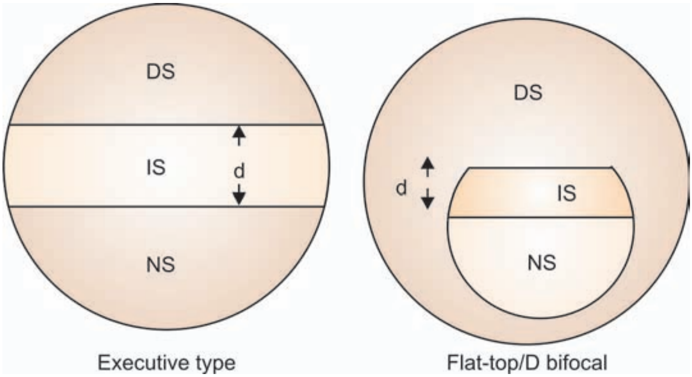


Fig. 14-12: Trifocal lens
DS = Distance segment
IS = Intermediate segment
NS = Near segment
d = Depth in mm

Progressive Addition Lens (PAL)

This is a spectacle lens with a gradual progressive change in power from distance to near as the patient's focus moves down the lens with negligible eye movement. It practically offers excellent vision at all distances and superior cosmetic appearance. Features of PAL (Fig. 14-13) are:

- Distance vision area in upper part of the lens.
- An intermediate narrow "transition" corridor of progressive area for distance to near vision.
- Near vision area in lower central part.
- Single vision lens appearance, i.e. absence of dividing lines giving enhanced cosmetic affect.
- Peripheral areas of the lens exhibit unwanted astigmatism and distortion. However, this area is intended for awareness of objects only. Since peripheral vision is disturbed by the optical distortion, eye movements are restricted.

Chronology of Invention of PAL: The conception of progressive addition lens is first conceived by Owen Aves in 1907. However, Henry Oxford Gowlland first made commercially available PAL under the trade name ULTIFO. The VARILUX progressive addition

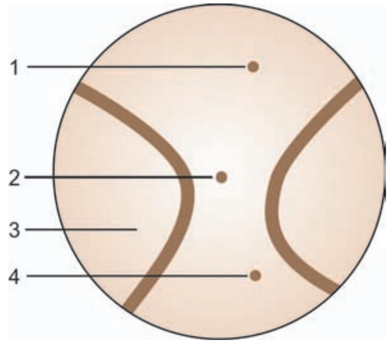


Fig. 14-13: Areas of a progressive addition lens (PAL). 1 = Distance vision area, 2 = Intermediate transition corridor, 3 = Periphery and 4 = Near vision area

lens from Essilor is designed by Bernard Maitenaz in 1959. Subsequently various manufacturers have modified and upgraded designs aiming at reduction of unwanted distortion and aberrations in the peripheral area.

Advantages of PAL

- Absence of image "Jump" which is experienced with bifocals and trifocals.
- Lack of a line in the lens which is cosmetically appealing to the wearer due to youthful appearance.
- Natural vision from distance to near.

Progressive addition lenses are supplied by the manufacturers, with few standard point markings, indicating key areas of the lens. This point marking of key areas helps the dispenser proper positioning and fitting of the lens (glazing) into the frame. Before delivery to the patient the marks are removed usually with thinner.

The centre of the reading area is conventionally inset 2.5 mm in relation to the fitting cross (Fig. 14-14). The fitting cross (+) corresponds to the centre of the pupil.

However, additionally some markings in the form of circles and logos (6, 8 in Fig. 14-14) are engraved on the progressive addition lenses. These engravings do not cause any visual interference and usually the wearer is also unaware of them. They are conventionally placed 34 mm apart across the 180° horizontal line

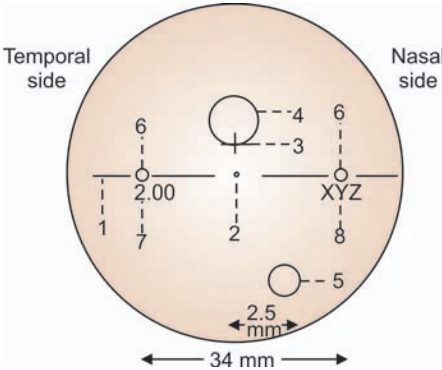


Fig. 14-14: Progressive addition lens blank–typical point marks and engravings. **1** = 180° horizontal line, **2** = Prism checking point (optical centre of the lens), **3** = Corresponds to patient's pupillary centre (fitting cross), **4** = Distance power spherical and astigmatism with axis checking point, **5** = Centre of reading area and power checking point, **6** = Engravings, **7** = Near addition (+2.00) and **8** = Manufacturer's logo (XYZ)

(6 in Fig. 14-14). Just below them one can locate engraved reading addition on the temporal side and occasionally the manufacturer's logo on the nasal side (7 and 8 in Fig. 14-14). Proper power dispensing and proper fitting of the progressive addition lenses into the frame for glazing is an essential criteria for optimum visual comfort.

Checking/Verification of power of PAL: Use of lensometer is the correct approach for this purpose. However, in PAL the checking areas are restricted and are designed for this particular purpose (Fig. 14-14).

- Distance power and axis–Area 4 of Fig. 14-14 (ignore any prismatic effects).
- Prism checking point–Area 2 of Fig. 14-14 (ignore power and axis readings).
- Near addition–Area 5 of Fig. 14-14.

Fitting procedure for PAL (specifications):

- Monocular P.D. (interpupillary distance) measurement–Accurate measurement with a pupillometer is essential.

- Distance from the centre of the pupil (fitting cross) to the lower edge of the lens (near recommended height)–This is measured with the chosen frame in place with the patient fixating on a distant object. In most PAL designs this recommended measurement is 22 mm. However, in some PAL designs this measurement can be as small as 16/18 mm (near recommended height).
- Each eye should be measured separately as an independent unit.
- Distance minimum height–It is the frame size in mm above the fitting cross (+). It is usually 12 mm but may be as low as 8 mm in some designs.

OPTICAL CENTRE OF LENS

Optical centre of a lens is point through which any incident ray passes undeviated.

HOW TO FIND OPTICAL CENTRE OF A LENS?

It is located by observing the image formed by a cross, i.e. two lines inclined at 90° to each other, viewed through the lens.

- Move the lens until one line of the cross remains undisplaced. A marker pen superimposed on this line of the cross draws a line on the lens.
- Now move the lens until the cross line at 90° remains undisplaced and repeat the process of marking on the lens surface.
- The point of the intersection of the lines drawn on the lens is the optical centre of the lens.

PUPILLARY (OR INTERPUPILLARY) DISTANCE

It is the distance between the centres of the pupils of the eyes. Monocular pupillary distance (MPD) is the distance from the median plane to the centre of each pupil. Monocular pupillary distance (MPD) measurement is a must for dispensing progressive addition lenses (PAL) since the face is often asymmetrical. PD measurement is a must for every pair of glasses irrespective of lens style and frame. It can be measured with either a PD rule or a pupillometer.

PD MEASUREMENT

For correct measurement the examiner's and the patient's eye level should be at the same horizontal plane.

PD Measurement with a PD Rule

- Monocular pupillary distance (MPD)–Take measurement (in millimetres) from the centre of the pupil to the centre of the bridge of the nose with the eyes looking straight ahead. Place "0" of the PD rule against the centre of the pupil.
- Binocular PD measurement–Ask the patient to focus his right eye at the examiner's left eye. Place the "0" of the PD rule against the centre of the pupil of the patient's right eye. The PD rule is placed along the horizontal diameter of the cornea. Now, ask the patient to focus his left eye at the examiner's right eye. The number in millimetres (mm) on the PD rule against the centre of left pupil of the patient is the binocular pupillary distance (Fig. 14-15).

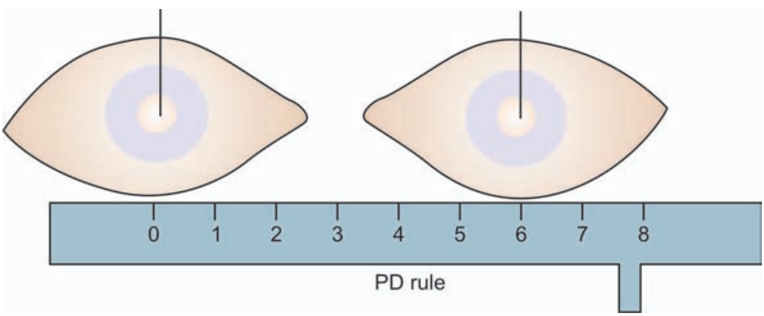


Fig. 14-15: Binocular PD measurement between the two pupillary centres – with PD rule

- Another way of measuring binocular pupillary distance is taking the measurement from the nasal limbus of one eye to the temporal limbus of another eye in horizontal plane (Fig. 14-16).

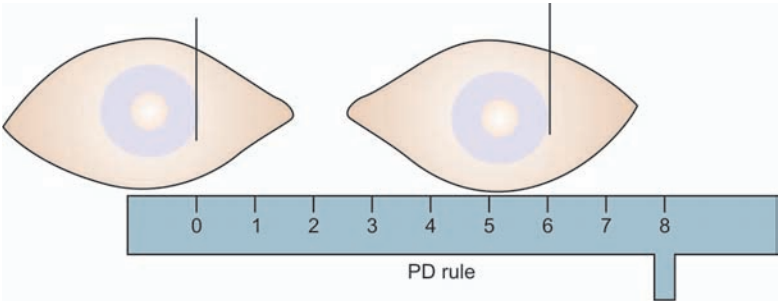


Fig. 14-16: Binocular PD measurement (alternative method)–with PD rule

PD Measurement with a Pupillometer

In pupillometer, the examiner moves a vertical line to align with the centre of the corneal reflections. An illuminated target is employed to fixate the patient's eye at infinity by interpolating a lens in front of the patient's eye (within the pupillometer). The pupillometer gives an accurate monocular and binocular PD reading in millimetres (mm).

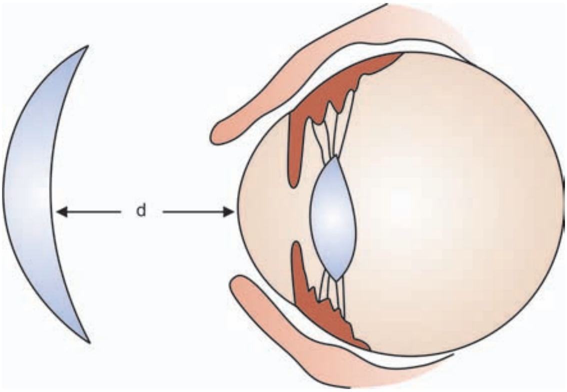


Fig. 14-17: Vertex distance
d = Vertex distance in mm

VERTEX DISTANCE

It is the distance between the back surface of the spectacle lens and the anterior corneal surface (Fig. 14-17). The vertex distance varies between 11 mm and 15 mm (average 12 mm). Vertex distance is important since the power of the glass changes depending on it's distance from the corneal apex. Hence, a patient's contact lens prescription differs from his spectacle prescription (See Table 15-2 in Chapter 15).

CHAPTER

15 Contact Lens

INTRODUCTION

Contact lens is an optical device designed to stay in contact with the cornea. Leonardo da Vinci was pioneer in describing optical principle of contact lens in Codex of the Eye, Manual D, published in 1508.

INDICATIONS

a. *Optical:* In majority of cases, contact lenses are used for optical purpose to correct refractive errors, i.e. myopia, hypermetropia, astigmatism, anisometropia, aphakia (particularly unilateral) and presbyopia. It is also used to correct irregular astigmatism and irregular corneal surfaces, i.e. in keratoconus.

b. *Cosmetic:*
   - To camouflage a blind eye with corneal scar with a painted contact lens.
   - To change the colour of the eye for cosmetic purpose.

c. *Therapeutic:*
   - To act as soft bandage contact lens in certain situations, e.g. corneal perforation, bullous keratopathy, recurrent corneal erosion, etc.
   - To prevent symblepharon in chemical burns, especially alkali burn.
   - To prevent amblyopia in anisometropia.
   - To focus the fundus or the trabecular meshwork (TM) during surgery or laser application.

- To prevent photophobia in patient's with aniridia and albinism with a contact lens (iris is painted peripherally with a clear central optical area).
- To prevent diplopia and help restore binocular vision in patients with unilateral aphakia or aphakia in one eye and pseudophakia in the other eye.
- To treat amblyopia to act as an occluder where conventional occlusion options are rejected by the patient.
- To accurately focus during laser therapy, particularly YAG laser, Argon laser, Diode laser for various indications along with slit lamp.
- To enhance colour perception in red-green deficient individual. X-chrom (corneal) contact lens and chromGen (soft) contact lens are used for this purpose.

d. *Diagnostic:* Various contact lenses are used along with slit lamp for diagnostic purposes.
   - Gonioscopic lenses–For gonioscopy.
   - Goldmann 3–Mirror contact lens–For gonioscopy and fundus examination.
   - Various fundus contact lenses.
   - Radioopaque contact lens for location of intraocular foreign body.
   - In ERG, an electrode is placed in contact with the cornea, often via a contact lens.

e. *Pharmacological:* Earlier, special contact lenses are soaked in drugs mainly pilocarpine for sustained release delivery of the drugs.

ADVANTAGES OVER SPECTACLES

- Field of view–Field of view is not restricted and the distortions which occur through the periphery of a spectacle lens are eliminated. However, small reduction of field of view may occur with smaller contact lenses, e.g. corneal (rigid) contact lens. Additionally, a rigid contact lens causes glare because of refraction through the periphery and edge of this smaller contact lens.

- Image magnification–Contact lens causes image magnification in myopes and image minification in hypermetropes and aphakics.
- Optical aberrations–Contact lens reduces optical aberrations arising from oblique, i.e. off–axis rays.
- Diplopia and binocular vision–Contact lens eliminates diplopia and ensures binocular vision in high anisometropia and uniocular aphakia by reducing aniseikonia compared to spectacles.
- Prismatic effect–Prismatic effect of spectacles is eliminated by the contact lens.
- Accommodation–Spectacle lenses of myopes incorporate a base–in prismatic effect which reduce accommodation and convergence necessary for near vision. Hence, if a myope with presbyopia switches from spectacles to contact lens, he suffers from greater demand of accommodation and convergence. This may cause eyestrain in these patients.
- The stigma of wearing spectacles is avoided and it is aesthetically pleasing to the patient.

OPTICS OF CONTACT LENSES

The precorneal tear-film smoothens corneal surface irregularities. Optically, precorneal tear-film and cornea may be considered as same refracting medium due to almost equal refractive indices. The layer of tear between the posterior surface of the contact lens and the anterior surface of the cornea is called "tear lens". The anterior surface of the cornea forms posterior surface of the "tear lens". The refractive power of the contact lens depends on the curvature of both the surfaces, thickness and refractive index of the material. In afocal lens the radius of the curvature of the two surfaces of the contact lens are equal. If the curvature of the cornea is same as that of the a focal lens the tear lens becomes of uniform thickness imparting a plano power (Fig. 15-1). In a contact lens with steeper base curve, the tear lens becomes more convex (Fig. 15-2). Similarly, in a contact lens with flatter base curve, the tear lens becomes more concave (Fig. 15-3).

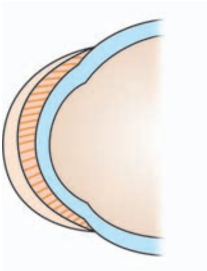


Fig. 15-1: Afocal lens with tear lens of uniform thickness

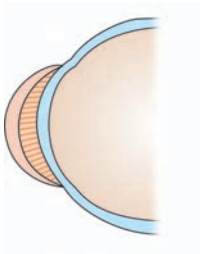


Fig. 15-2: Steeply fitting contact lens (convex tear lens)

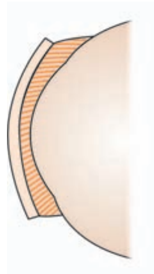


Fig. 15-3: Flatter fitting contact lens (concave tear lens)

TYPES OF CONTACT LENSES

Contact lenses can be broadly classified into scleral, semiscleral (or soft or hydrogel) and corneal (or rigid) types.

Contact lenses can also be categorised depending on the back curve into monocurve, bicurve and tricurve. The shape of the curvature of the posterior surface of the contact lens should be aspheric enough to closely conform to the contour of the anterior surface of the cornea. This is essential for good fit. In bicurve and tricurve contact lens, one or two concentric base curves of increasing radius of curvature are blended with the central optic zone.

Depending on the oxygen transmissibility the contact lenses can also be classified as:

Low – less than 12 Dk/cm
Moderate – 12 to 34 Dk/cm
High – 35 to 100 DK/cm.

SCLERAL CONTACT LENS

- They are usually made of PMMA (polymethyl methacrylate).
- However, they are totally impermeable to oxygen which is essential for corneal metabolism and corneal health.
- They are now gradually replaced by rigid gas permeable (RGP) materials.
- Scleral lenses are indicated particularly in keratoconus, irregular corneal surfaces and ocular surface disorders.

- The scleral contact lens diameter varies from 23 to 25 mm and the central optical zone diameter varies from 11.5 to 13.5 mm.

SEMISCLERAL (OR SOFT OR HYDROGEL) CONTACT LENS

- These most popular contact lenses are designed to cover cornea, limbus and 1.5 to 2 mm of the adjacent sclera.
- They are very comfortable and the fitting procedure is very simple.
- Their diameter varies from 13.5 to 14.5 mm.
- They are initially made of hydrophilic material HEMA (hydroxyethyl methacrylate). HEMA is hydrophilic due to it's free hydroxyl group which binds with the water. However, HEMA's water content is only 38% and low Dk value of 9 is not sufficient to maintain corneal metabolism efficiently. The oxygen permeability (Dk) is directly linked to it's water content.
- Hence, subsequently other monomers such as methacrylic acid (MA), N-vinyl pyrrolidone (NVP), methyl methacrylate (MMA) etc. are added in various percentage combinations.
- Methacrylic acid (MA) enhances the water content due to additional hydroxyl group.
- N-vinyl pyrrolidone (NVP) increases water content due to a carboxyl group which attracts water.
- Methyl methacrylate (MMA) provides strength, rigidity and superior optical quality.
- Soft contact lenses are used for optical purpose and as therapeutic soft bandage contact lens.
- Soft contact lenses are available commercially as daily disposable, monthly disposable, extended wear (EW) and daily wear schedules.
- Soft contact lens can correct astigmatism upto only 1.00D, since they adapt to the contour of the cornea.
- Advantages–Minimum adaptation time, inexpensive, available with different cosmetic tints, available in different wearing schedules and ideal for sportsman.
- Disadvantages–Cannot correct astigmatism of more than 1.00D and requires complex care procedure.

However, soft toric lenses are slowly gaining popularity which are designed to correct astigmatism. Toric soft lenses have axis notation marks engraved along their horizontal and or vertical meridian. These axis notation marks act as a reference line for the practitioner for accurate optical correction.

Silicon hydrogel soft contact lenses were developed to overcome the complication of chronic hypoxia in extended wear (EW) lenses. Silicon hydrogel contact lens is made by combining silicon rubber with hydrogel polymer. It does not adhere to the cornea like the basic silicon rubber. They have water content of 25 to 45% and Dk (or Barrer unit) of 110 to 175. In silicon hydrogel lenses, water content is inversely proportional to oxygen transmissibility (Dk/t). Silicon hydrogel lens combines oxygen transmissibility of the silicon with the hydrophilic property of the hydrogel.

CORNEAL (OR RIGID) CONTACT LENS

- Initially, they are made of PMMA only. They are now made of combination of PMMA, silicon, fluorocarbon, methacrylic acid (MA) and PVP (polyvinyl pyrrolidone) in various percentage to offer different oxygen permeability and surface wetting property.
- The lens diameter varies from 8.5 to 9.5 mm and allows oxygen permeability due to coverage of smaller area of corneal surface.
- They are easy to fit.
- Rigid contact lens can correct corneal astigmatism of larger diopter.
- Advantages—Quality of vision is better, more resistance to deposits, easy to insert and remove, cost is less, oxygen permeability is more than other types, significant degree of astigmatism can be corrected and suitable for patients with ocular surface disorders.
- Disadvantages—Period of adaptation is longer and approximately three weeks, less comfortable than soft contact lens.

FITTING PROCEDURES

GENERAL PRINCIPLES

- The contact lens practitioner or the patient handling the contact lens should wash hands and dry them always prior to lens insertion.
- The procedures are described assuming the practitioner or the patient is right handed. However, if the patient and the practitioner are left handed opposite arrangement will be applicable.
- If the practitioner is right handed he should stand on the right side of the patient (applicable only to the practitioner).

SCLERAL

Insertion

- The patient is asked to bend forward and look downwards.
- Hold the contact lens between the thumb and the index finger of the right hand with the lens being horizontal and filled with saline solution.
- Retract the upper lid of the patient away from the globe with the left hand using the thumb and the index finger to pull on the eyelashes.
- Now, place the superior edge of the scleral contact lens under the upper eyelid and keep it in place firmly with the left hand by closing the upper lid over the lens.
- Evert the lower lid using the right hand over the inferior edge of the contact lens.

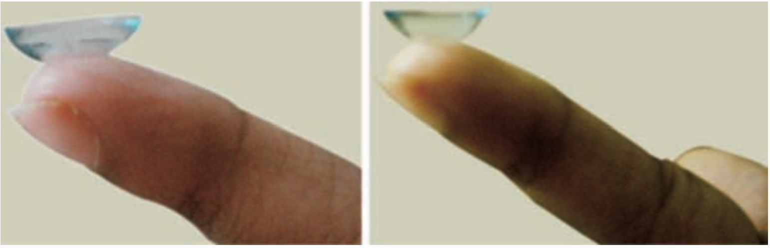
Removal

- Retract the upper lid using the thumb or the index finger of the left hand and press the lid margin behind the superior edge of the scleral contact lens.
- Move the upper eyelid over the globe temporally to release the suction force between the contact lens and the globe.
- Ask the patient to move the eye upwards and the lens is easily released from the eyeball.

SOFT CONTACT LENS

Insertion

- Place the lens on the palm of the right hand and rinse with the solution to remove debris by rotating the lens clockwise thrice.
- Drain the excess solution before placing the soft lens on the tip of the index finger of right hand. The fingertip should be as dry as possible. The dictum is "dry finger and wet lens".
- Before insertion verify whether the lens is inside out or not by examining lens profile (Figs 15-4A and B). In inside-out lens the bottom will be slightly flattened and the edge will be slightly turned-out.
- If the lens is inserted in inverted shape (inside-out) the patient will complain of little discomfort, unstable vision and excessive movement of the lens.
- Retract the upper lid firmly with the middle finger and ring finger of the left hand (approaching from above).
- Now retract the lower lid with the ring or middle finger of the right hand and ask the patient to look up and in, i.e. nasally.
- Place the soft lens on the exposed temporal bulbar conjunctiva (Fig. 15-5A).
- The lens is centred on the cornea by asking the patient to look towards the lens.
- Ask the patient to look to the right and left and close eyelids slowly and move eyeballs in all directions under the closed eyelids.



Figs 15-4A and B: (A) Contact lens properly oriented (Shaped like a dish) and (B) Contact lens inside-out (inverted—shaped like a bowl)

Fig. 15-5A: Soft lens—Insertion

Fig. 15-5B: Soft lens—Removal

Removal

- Retract the upper and lower lid similarly and look upwards.
- Decentre the lens temporally on the sclera by using the index finger.
- Pinch and take the lens off the scleral surface by using the thumb and the index finger of the right hand (Fig. 15-5B).

RIGID CONTACT LENS

Insertion

- Stand on the right side of the patient (applicable only to practitioner).
- Ask the patient to look straight at a distant object.
- Place the rigid contact lens on the tip of the index finger of the right hand. Not more than a drop of wetting solution is to be applied to the lens.
- Retract the upper lid using the middle and ring finger of the left hand (approaching from above).
- Retract the lower lid with ring or middle finger of the right hand and place the contact lens onto the cornea.
- Ask the patient to blink and remove only the right hand retracting the lower lid and ask the patient to look down.
- Now release the retraction of the upper lid.
- The patiently is priorly warned that after release of the upper eyelid he will face discomfort due to irritation of the upper eyelid margin.
- The patient is asked to raise his chin and look down. This posture will help in stabilising the lens and reducing initial discomfort.

Removal

- Place the index finger of the right hand on the middle of the upper lid and middle finger of the right hand on the middle of the lower lid and pull the eyelids apart temporally, i.e. away from the nose.
- Place the left hand like a cup against the check.
- Now blink firmly and the lens will be flipped out of the eye by the tightened eyelids into the cupped left hand.

CONTACT LENS RELATED INFORMATIONS AND TERMINOLOGIES

BOZR–Back optic zone radius

BOZD–Back optic zone diameter

TD–Total diameter

FVP–Front vertex power

BVP–Back vertex power

BC–Base curve—It is the curve of the anterior, i.e. front surface of the contact lens.

Barrer/Dk—It is a unit of oxygen permeability of a contact lens. D stands for diffusion coefficient of oxygen through the material and k stands for the solubility of oxygen in the material. The units of Dk are also known as "Barrer" or "Fatt" units.

Diffusion coefficient—The speed at which oxygen molecules pass through the contact lens material.

Solubility—The number of oxygen molecules which can be absorbed in a given volume of the contact lens material.

Hence, a contact lens with lower water content has lower Dk value, whereas those with higher water content have higher Dk values.

Oxygen transmissibility = Dk/t

Oxygen transmissibility is inversely proportional to the thickness (t in cm) of the contact lens and directly proportional to the oxygen permeability of the contact lens material (Dk or Barrer).

Daily wear contact lens—Contact lenses that are worn daily for 10 to 12 hours. They are kept in a container immersed in a specified solution when not in use. They have to be cleansed daily before wearing. They are usually replaced annually.

Extended wear (EW) contact lens—Contact lenses that can be worn continuously for a period of 1 to 7 days. They have to be cleansed after removal and kept in a container immersed in specified solution before subsequent wearing. Nowadays, silicon hydrogel soft contact lens and RGP contact lens are available for continuous wear upto 30 days (day and night). Silicon hydrogel lenses are safer than conventional soft lenses for extended wear. There is increased incidence of infectious keratitis with conventional soft extended wear contact lenses than conventional soft daily wear lenses.

Disposable contact lenses—Daily and monthly disposable soft contact lenses are also available.

Cosmetic contact lens—These soft contact lenses change the colour of the eyes and are available in various tints. Such lenses have a clear central optical area (approx. 4 mm) and a clear peripheral area of 1 mm overlying the sclera. Contact lenses with very light blue tint are available for easier handling.

Bifocal contact lens—Various designs of bifocal soft contact lens and multifocal soft contact lens are indicated in presbyopic, aphakic and pseudophakic patients due to reduced or lack of accommodation. Various types of bifocal contact lenses are available:

i. Annular—The central zone is meant for distance vision with a surrounding annular zone intended for near vision.
ii. Segmental—It contains the near addition in the lower segment of the contact lens. Segmental bifocal contact lens is prevented from rotation usually by truncation.
iii. Diffractive—It consists of series of concentric diffraction rings in the centre of the back surface. The diffraction rings are designed to focus equally on the retina from distant and near objects without any movement of the contact lens.
iv. Aspheric—The central area of the multifocal contact lens is intended for distant vision. There is a gradient transition of power from the centre to the periphery to correct all range of vision.

In annular and segmental variety during down gaze, the contact lens rises relative to the cornea, positioning the near segment in the visual axis. Another method of correction is used earlier, instead of bifocal contact lens, termed "Monovision". In "monovision" the eye with better vision is fitted with a distance contact lens correction, whereas the other eye is fitted with a near contact lens correction.

ASSESSMENT OF SOFT CONTACT LENS FITTING

- *Initial comfort*: Initially, both a well-fitting lens and a tight-fitting lens are comfortable. A loose fitting lens gives rise to discomfort and awareness of the lens due to excess movement of the lens and poor centration. However, a slight awareness of the lens is considered optimum comfort.

- *Vision:* Stable good vision indicates good lens centration and good tear film stability.
- *Lens centration:* If the edge of the lens symmetrically overlaps on the sclera on all sides the centration of the lens is optimum.
- *Lens movement:* At least 0.3 mm of lens movement is required with each blink for adequate tearfilm lubrication. Tight fitting lenses show little or no movement (less than 0.1 mm) whereas loose fitting lenses show excessive movement (more than 1.0 mm).
- *Lag on upgaze and version:* A well-fitting lens will decentre between 0.3 to 0.7 mm upon upgaze or lateral version, i.e. abduction and adduction. However, excess of decentration indicates loose fitting lens while absence of decentration indicates tight-fitting lens.
- *Push-up test:* This test is an indicator of the mobility of the contact lens in response to a push upwards on the inferior edge of the lens through the lower eyelid margin. A well-fitting contact lens moves easily and regains centration quickly.
- *Fluorescein stain pattern: It is not done in soft contact lens fitting since it is absorbed by the soft contact lens*. However, it can be used to trace lost soft contact lens or fragment of soft contact lens under the upper eyelid or upper conjunctival fornix.

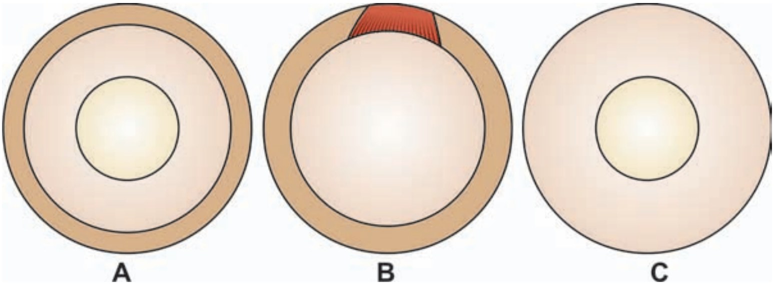
ASSESSMENT OF RIGID CONTACT LENS FITTING

- *Comfort:* Around 3 weeks are required for adaptation to the lens. The lens edge is at fault if it remains uncomfortable beyond 3 weeks.
- *Vision:* The vision should be stable during blinking.
- *Centration:* The rigid lenses are 2.5 mm smaller in diameter than the horizontal visible iris diameter and they should be perfectly centred over the pupil between blinks. Temporal or nasal decentration of the rigid contact lens indicates a flat fit. A high riding lens or a low riding lens also indicates a too flat fit attributed to the back optic zone radius (BOZR).

- *Lens movement:* Excessive movement indicates flat fit. Restricted movement indicates steep fit. Ideally, after a blink the rigid contact lens should move down straight slowly. During horizontal gaze, the lens should stay within the limbus. During blinking, excursion of the lens should be between 2 to 2.5 mm.
- Fluorescein stain pattern—It is observed through the slit-lamp with cobalt blue filter to assess lens fit and corneal desiccation (Table 15-1 and Figs 15-6A to C). In areas of touch, between the contact lens and the cornea, fluorescein will be absent and the area will appear dark (Fig. 15-6B).

Table 15-1: Fluorescein stain pattern in rigid contact lens fitting

Good Fit (Fig. 15-6A)	*Flat Fit (Fig. 15-6B)*	*Steep Fit (Fig. 15-6C)*
Light staining in central area	Absent staining in the central area indicating central touch	Pooling of fluorescein in the central area
Absent staining in mid peripheral area	Pooling of fluorescein in the periphery	
Band of staining under the peripheral edge indicating edge lift	Apical touch, i.e. appears dark with absence of fluorescein	



Figs 15-6A to C: (A) Good fit-fluorescein stain pattern, (B) Flat fit-fluorescein stain pattern and (C) Steep fit-fluorescein stain pattern

DETERMINATION OF CONTACT LENS POWER

Spectacle lenses are placed at a vertex distance of usually 12 mm from the corneal apex, whereas contact lenses are worn at a vertex distance of practically 0 mm. We are also aware that if a concave lens is brought closer to the eye its effective strength increases, whereas converse is true for convex lenses. So, power of a concave lens decreases, whereas power of a convex lens increases for conversion to contact lens power. Hence, the refractive error at the spectacles plan, must be converted to the refractive error at the corneal plane from the vertex conversion table (Table 15-2).

Table 15-2: Vertex conversion table*

–		+	–		+	–		+
3.25	-	3.00	7.37	-	6.75	12.50	-	10.75
3.50	-	3.25	7.50	-	6.87	12.75	-	11.00
3.75	-	3.37	7.62	-	7.00	13.00	-	11.25
4.00	-	3.75	7.75	-	7.12	13.50	-	11.50
4.25	-	3.87	7.87	-	7.25	13.75	-	11.75
4.50	-	4.12	8.00	-	7.37	14.00	-	12.00
4.75	-	4.50	8.12	-	7.50	14.25	-	12.25
5.00	-	4.75	8.25	-	7.62	14.75	-	12.50
5.12	-	4.87	8.50	-	7.75	15.00	-	12.75
5.37	-	5.00	8.75	-	8.00	15.50	-	13.00
5.50	-	5.12	9.00	-	8.25	15.75	-	13.25
5.62	-	5.25	9.25	-	8.37	16.25	-	13.50
5.75	-	5.37	9.50	-	8.62	16.75	-	13.75
5.87	-	5.50	9.75	-	8.75	17.00	-	14.00
6.00	-	5.62	10.00	-	9.00	17.25	-	14.25
6.12	-	5.75	10.25	-	9.12	17.62	-	14.37
6.37	-	5.87	10.50	-	9.25	18.00	-	14.50
6.50	-	6.00	10.75	-	9.37	18.12	-	14.75
6.62	-	6.12	11.00	-	9.62	18.50	-	15.00
6.75	-	6.25	11.25	-	9.75	18.75	-	15.25
6.87	-	6.37	11.50	-	10.00	19.00	-	15.50
7.00	-	6.50	11.75	-	10.25	19.50	-	15.75
7.12	-	6.62	12.00	-	10.37	20.00	-	16.00

*Average 12 mm Vertex Distance. For Minus Powers Read left to right and for Plus Powers Read right to left.

COMPLICATIONS OF CONTACT LENS WEAR

Contact lens is a popular alternative to spectacle for correction of refractive error. However, it is not free from complications. Major complications of clinical significance are discussed below:

CONJUNCTIVAL COMPLICATIONS

i. Giant papillary conjunctivitis (GPC)—It involves the upper tarsal conjunctiva, caused by both mechanical irritation and immunological reaction to the protein deposits on the contact lens. The papillae are more than 1 mm in diameter in GPC. They are accompanied by hyperaemia, mucoid strands, lid oedema and heavy lens deposits.
ii. Conjunctival, limbal hyperaemia and conjunctival chemosis– These occur often in a allergic or toxic response to the disinfectants present in the lens care solutions, e.g. thimerosal, benzalkonium chloride, etc.

CORNEAL COMPLICATIONS

i. *Oedema:* It may involve both the epithelium (Sattler's veil) and the stroma. It is caused by hypoxia resulting in disruption of transport mechanism of epithelium and endothelium and stromal ion balance. Stromal swelling results in endothelial fold seen as dark lines in specular reflection. Stromal striae are also seen in posterior stroma as fine, white vertical lines (Fig. 15-7A).
ii. *Microcysts:* They are very minute, transparent and irregularly scattered cysts (Fig. 15-7B) appearing in response to induced hypoxia. They represent dead cellular debris near the epithelial basement membrane. They can be seen in retroillumination technique of slit-lamp biomicroscopy. They migrate anteriorly in 8 to 12 weeks and cause punctate epithelial keratopathy which can be stained with fluorescein.
iii. *Vascularisation:* Vascularisation occurs due to hypoxia, microtrauma and inflammatory stimulation. Superficial vascularisation, i.e. encroachment of blood vessels into the superficial cornea is more common than the deep one. These

vessels are continuous with the limbal vessels (Fig. 15-7C) and involves the superior limbus most frequently. However, deep vascularisation (Fig. 15-7D) is very uncommon and rare with contact lens wearer.

iv. *Endothelial changes:* Polymegathism, i.e. greater than normal variation in cell size in endothelial mosaic is linked to chronic hypoxia of the cornea of long duration. They are seen in specular reflection of slit-lamp biomicroscopy (Fig. 15-7E). Endothelial blebs are intracellular accumulation of oedema due to hypoxia and acidosis and seen as black dots in specular reflection.

v. *Contact lens induced acute red eye (CLARE) syndrome:* It is an acute inflammatory response seen in soft extended wear contact lens and extended wear hydrogel lens worn tightly. Large infiltrates are seen in anterior stroma peripherally. The patient complains of severe ocular pain, photophobia, lacrimation and redness. Cellular debris is trapped behind the lens rendering it adherent, i.e. immobile. CLARE syndrome is caused by toxic effects of entrapped cellular debris, dehydration of tearfilm during sleep and toxicity to contact lens solution preservative. Treatment is discontinuation of the contact lens wearing, topical steroid with antibiotic application and switch over to a daily wear lens after remission of the syndrome.

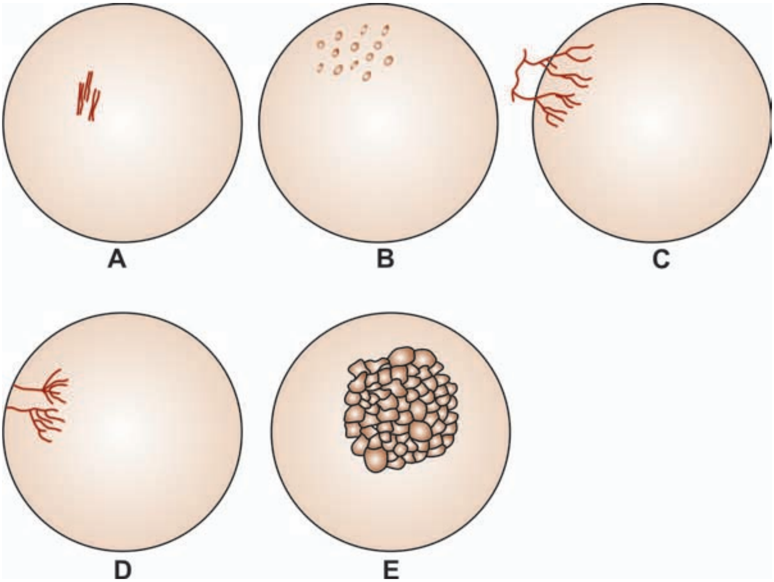
vi. *Infection*: Pain associated with discharge and redness is a warning sign for possibility of corneal infection. Acanthamoebae keratitis is a rare, serious blinding infection seen more commonly in contact lens wearer. Acanthamoebae is found in soil, chlorinated water, swimming pool, contact lens solutions, etc. Extreme ocular pain disproportionate to the clinical signs is a prominent sign of Acanthamoebae keratitis.

PHYSICAL PROBLEMS OF CONTACT LENS

i. Loss of contact lens
ii. Lens deposits.

PROBLEM OF CONTACT LENS CARE SOLUTION

i. Allergy–Hypersensitivity to thimerosal is very common.
ii. Toxicity
iii. Adverse ocular response
iv. Lens surface deposits–Chlorhexidine binds to the mucin to form lens surface deposits.



Figs 15-7A to E: (A) Corneal stromal striae, (B) Microcysts, (C) Superficial corneal vascularisation, (D) Deep corneal vascularisation and (E) Polymegathism of endothelial mosaic

Section 6

Special Chapters

CHAPTER

16 Ophthalmic Instrumentation

INTRODUCTION

This chapter highlights the basic principles, examination techniques of common instruments used in ophthalmology. The instruments are:

- Slit-lamp biomicroscope and vital stains
- Tonometry
- Gonioscopy
- Indirect biomicroscopy
- Geneva lens measure
- Keratometer
- Lensometer
- Direct ophthalmoscope.

SLIT-LAMP BIOMICROSCOPE

It offers a magnified, stereoscopic, noninvasive and detailed view of the anterior segment of the eye. However, in conjunction with some accessory optical lenses, it can be used for detailed examination of the angle of the anterior chamber (gonioscopy), measurement of intraocular pressure (applanation tonometry) and minute examination of the retina (biomicroscopic indirect ophthalmoscopy). Different types of lasers (YAG, Frequency–doubled YAG, Argon, Diode, etc.) are also delivered through slit-lamp for therapeutic purpose. Vital staining of cornea and conjunctiva is also observed through slit-lamp biomicroscope.

Slit-lamp examination is done in a room semidarkened or darkened, free from dust, humidity and heat. The patient should be comfortably seated in a revolving stool with his chin and forehead pressed against chinrest and head rest respectively. Mastering the art of slit-lamp examination is a prerequisite for a good ophthalmologist and an efficient optometrist.

SALIENT TECHNICAL INFORMATIONS

- Nomenclature–Since the *microscope* has two eyepieces, it is binocular and offers the observer a *binocular*, stereoscopic and magnified view of the eye. Further, the light beam can be made very narrow producing a *slit* of light. Hence, *it is called slit-lamp biomicroscope (Fig. 16-1).*
- Magnification–Magnification of image is obtained by multiplying the power of the oculars with the power of the objective lens. Thus, if the oculars are of 10X strength and the objective lens is of 2.5X, the resultant magnification will be 25X. Majority of slit-lamp biomicroscope are usually available with magnifications between 8X and 40X with intermediate magnifications of 12X, 16X and 25X. Magnification is changed by either changing the objective lens or by replacing the oculars, i.e. eyepieces. Objective lens is changed by either turning a dial on the side of the observation system or flipping a lever located below the observation system.
- Focussing–Focussing is controlled by a joystick. It is designed to move the slit-lamp biomicroscope laterally, axially and vertically. Vertical movement is controlled by rotating the joystick.
- Intensity of light–The illumination is controlled either by a rheostat or by rotating a knob. The height, diameter of the light beam can be altered by another knob. The width of the light beam is also controlled by another knob, located in the lower end of the illumination system.
- Click-stop position–A "click-stop" position indicates that the illumination system and the observation system are coaxial.
- The illumination system or light source can be moved away from the observation system, to change the angle of the incident light beam which is essential for various types of illumination techniques, discussed later in this chapter.

- A frosted ground glass (if present) can be positioned in the path of the incident light by flipping a lever in the diffuse illumination technique.
- Halogen light is used in most of the examinations. Coloured filters (cobalt blue, red free, i.e. green) can be used by sliding a knob for procedures discussed later.

Fig. 16-1: Slit-lamp AIA–11 5 step, inset showing observation system of Slit-lamp AIA–11 2 step (photo courtesy Appasamy Associates, India)

DIFFERENT TECHNIQUES OF ILLUMINATION

Diffuse Illumination (wide beam)

- The diffuse illumination is provided by placing a frosted or ground glass filter in front of the focussed light beam of slit-lamp biomicroscope (Fig. 16-2).
- Usually, in diffuse illumination the incident light is projected into the eye obliquely (45°) and viewed under low magnification.
- The light will be defocussed and will provide even illumination over the entire field of view of opaque tissues of the anterior segment (sclera, iris, eyelid margins, bulbar conjunctiva, etc).

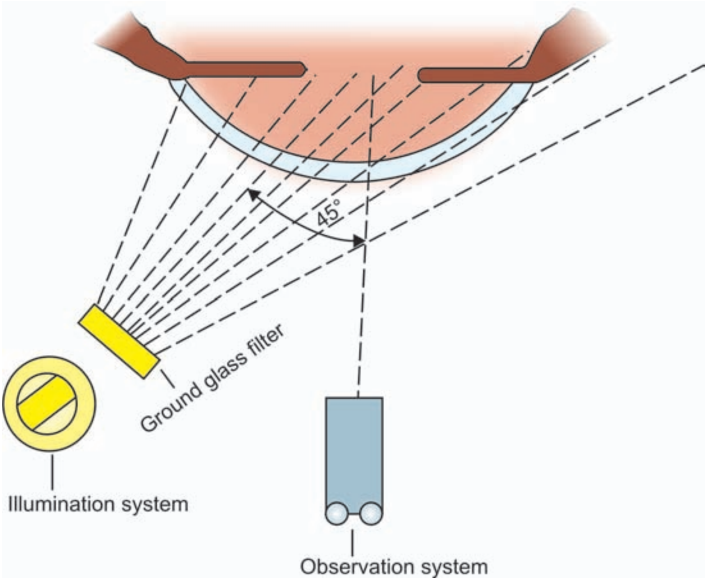


Fig. 16-2: Slit-lamp biomicroscopy—Diffuse illumination

Direct Illumination

This technique refers to viewing of structures within the focussed light beam. The type of direct illumination varies according to height, width of the light beam, angle of the incident light and angle between incident light beam and observation system.

i. *Optical section*

- The beam is very narrow and slit.
- The light beam is projected obliquely. The angle between oculars and illumination source is 30 to 60°. The more is the angle, the more wide is the optical section (parallelepiped).
- It gives a cross section view of different layers of the cornea (Fig. 16-3).
- In dilated pupil, it is possible to see the lens and anterior third of the vitreous in optical section with light beam being brightest in an absolutely dark room (Fig. 16-3).
- It is used to locate the site of a corneal lesion, scar, foreign body and depth of anterior chamber (Van Herick-Shaffer technique, see later in this chapter).

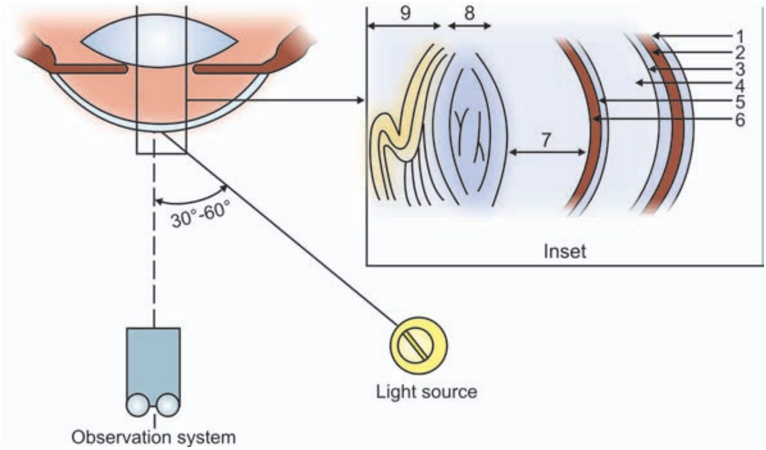


Fig. 16-3: Slit-lamp biomicroscopy—Optical section of ocular structures. Inset showing different layers of the cornea (schematic). **1** = Tear film–bright, **2** = Epithelium–dark, **3** = Bowman's membrane–bright, **4** = Stroma–wide zone, **5** = Descemet's membrane–bright, **6** = Endothelium–dark, **7** = Anterior chamber, **8** = Lens and **9** = Vitreous humour

ii. *Conical/pinpoint illumination*

- The light beam is very narrow and short and the light beam is focussed into the aqueous *against dark pupillary background* to enhance the contrast. *The room should be absolutely dark*.
- It is used to detect "aqueous flare" and "cells" in the anterior chamber in iritis.
- The optical section may be similarly used to detect flare and cells in anterior chamber. *Aqueous flare* appears as *yellowish particles* and *cells* in anterior chamber appear as *whitish reflections*.
- Cells in the tear meniscus may be similarly observed against background of iris by pushing the lower lid up.

iii. *Specular Reflection*

- The angle of the illumination source must be set to equal the angle of the oculars (Fig. 16-4).
- It is used to visualise corneal endothelium.
- The illumination beam is parallelepiped, i.e. a wider optical section (corneal width).

- First start with lower magnification and focus the corneal surface. Now move the oculars 20° to 30° away from the illumination source. Then, move the illumination source 20° to 30° on the opposite direction until a bright mirror-like reflection is seen through one ocular, i.e. eyepiece. Specular image is seen at every interface between structures of different refractive index. Hence, there should be three reflexes (Fig. 16-4);

Specular reflection

- bright reflection from tearfilm
- dim reflection from endothelium
- blurred image of light source

- Focus finely on the intermediate dim reflection to observe endothelial mosaic. *Endothelium is best seen using only one ocular*.
- Now the magnification may be increased to view the endothelial cells.

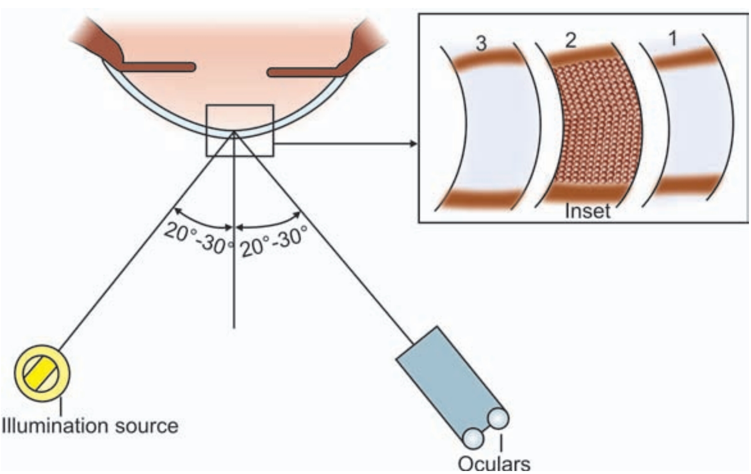


Fig. 16-4: Slit-lamp technique—Specular reflection, inset shows specular reflections with the endothelium in focus (schematic). **1** = Tear film–bright reflection, **2** = Endothelial mosaic–dim reflection and **3** = Light source–blurred image

iv. *Tangential or oblique illumination*

- In this technique, the angle between the observation system and illumination source is set at 90° (Fig. 16-5).

- It produces long shadows for any elevation particularly on the iris surface. Even depressions are better appreciated.

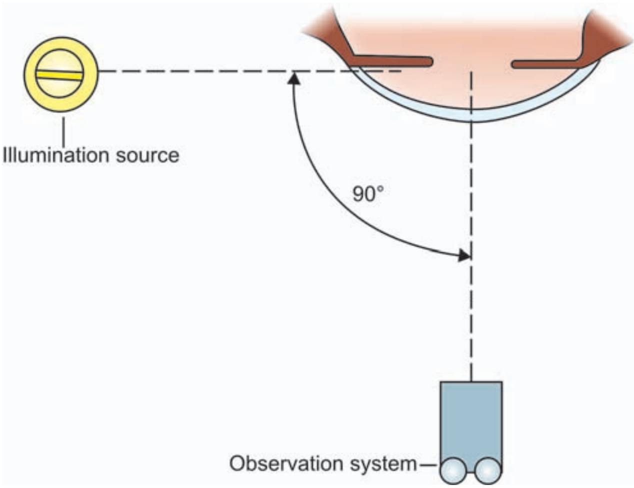


Fig. 16-5: Slit-lamp technique—Tangential illumination

Indirect Illumination

In this technique the area of interest is viewed indirectly by an illumination from reflected light of the direct beam, i.e. *structures not within the focussed light beam are under observation*.

i. *Proximal illumination*
- A moderately wide light beam is focussed on the areas adjacent to the lesion of interest (Fig. 16-6).
- The lesion is observed with scattered light against dark background. This results in a higher contrast of the lesion against a dark pupil.

ii. *Sclerotic scatter*
- A parallelepiped illumination beam is focussed at the temporal limbus.
- Illumination beam is set at an angle between 45° and 60° with the observation system, i.e. the microscope is focussed centrally on the cornea.

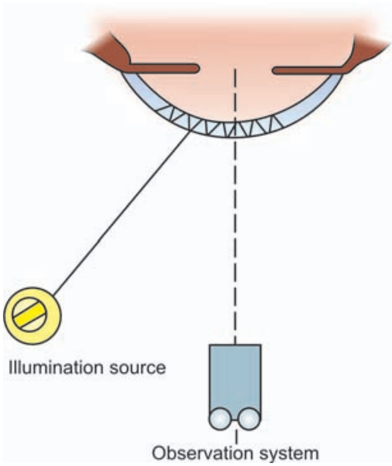


Fig. 16-6: Slit-lamp technique—Proximal illumination

- The slit-lamp light beam undergoes total internal reflection within the corneal substance and reaches opposite limbus (Fig. 16-7).
- This produces a bright circumcorneal glow with the cornea being dark.
- A scar or lesion within the cornea will be visible by scattering of light against dark papillary background.

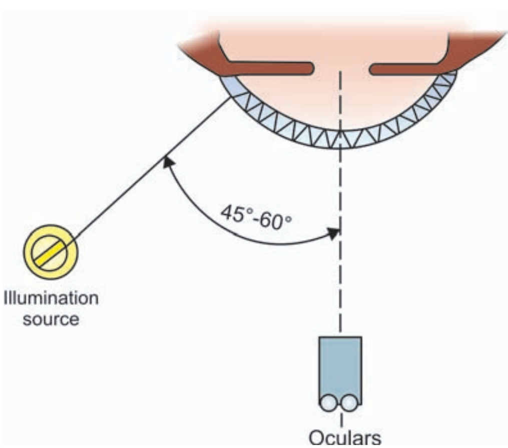


Fig. 16-7: Slit-lamp technique—Sclerotic scatter

Retroillumination

- In this technique, the incident light beam is reflected from the iris, anterior lens surface or retina to illuminate more anteriorly located structures of interest.

i. *Direct retroillumination*

- This refers to viewing the structure against an *illuminated background*.
- In direct retroillumination corneal opacities appear black against an *illuminated background*. Posterior capsular opacities or lental opacities appear dark against red glow of retina.
- The light beam should be directed from 45° angle and focussed behind the area of interest (Fig.16-8).
- *In direct retroillumination objects that normally appear bright will appear dark.*

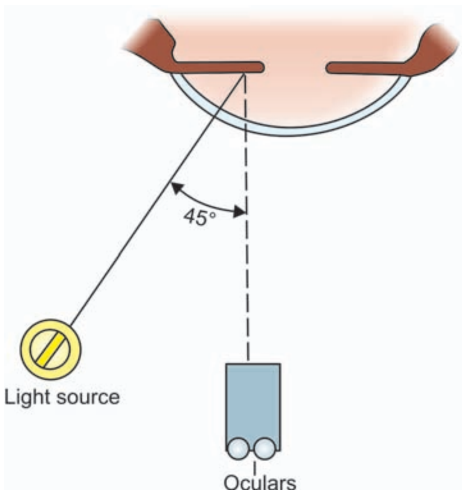


Fig.16-8: Slit-lamp technique—Direct retroillumination

ii. *Indirect retroillumination*

- This refers to viewing the structures of interest against a *dark background*.
- The light beam is positioned in such way that the dark background is behind the structure of interest (Fig. 16-9).

- The structure should not be within the pathway of the reflected light.

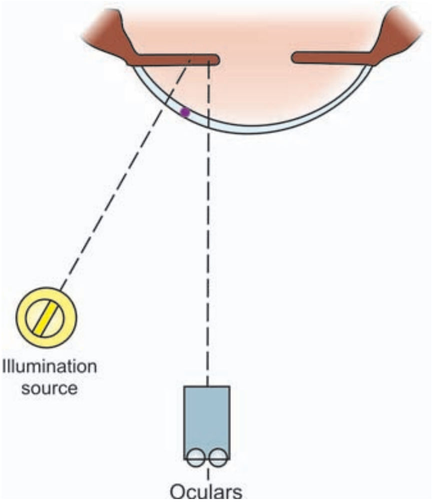


Fig.16-9: Slit-lamp technique—Indirect retroillumination
• = Corneal opacity

iii. *Transillumination*
- In transillumination the iris tissue is tested for passage of light through a defect within it.
- The slit-lamp light source and the microscope is positioned coaxially, i.e. click-stop position (Fig. 16-10) and focussed on the iris surface.
- Use a circular light beam equal to pupillary size and project through the pupil.
- Use lower magnification.

USE OF FILTERS IN SLIT-LAMP BIOMICROSCOPE

a. *Cobalt blue filter:* It is used in applanation tonometry, assessment of rigid contact lens fitting and fluorescein staining of cornea. It should be kept in mind that significant amount of light has been filtered out by the cobalt blue filter. Hence, brighter illumination should be employed while using cobalt blue filter.

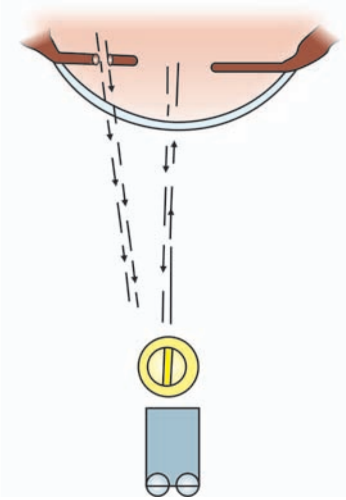


Fig.16-10: Slit-lamp technique—transillumination

b. *Red free filter (Green):* It blocks all red wavelengths. So, blood vessels, microaneurysms and haemorrhages will appear as dark against a green background.
c. *Yellow filter:* It significantly enhances contrast by eliminating the blue light reflected from the cornea.

Both cobalt blue and red free (green filters) are also useful in the study of the vitreous. Blue and green lights are scattered more than the red light due to shorter wavelength. Gel structure of the vitreous becomes more visible in incident scattered light. Additionally, blue or green filter provides a dark fundus background for examining the vitreous.

CARE AND MAINTENANCE

- It should be kept in a room free of dust, humidity and direct exposure to sunlight.
- It should be covered at the end of the examination.
- Remove the electrical connection plug from the socket before changing the fuse or bulb.
- Do not touch the lenses, mirror and glass portion of the bulb. Remove accidental fingerprints on these with tissue paper.

- Always operate the instrument in lower voltage setting, i.e. in lower illumination to increase the lifespan of the bulb.

VITAL STAINS

Slit-lamp is an essential tool to examine the cornea and conjunctiva after staining them with different vital stains.

Sodium Fluorescein

- It is a yellowish—red dye and it stains only *tearfilm*.
- It is seen as bright yellow with cobalt blue filter.
- Instill one drop of proparacaine HCl (0.5%) in conjunctival sac. Touch the tear meniscus with fluorescein strip. Wipe the excess fluorescein with tissue paper from the closed lid margin. Ask the patient to blink at least thrice and wait for one to two minutes for better penetration.
- Examine the cornea through the slit-lamp with cobalt blue filter in place.
- Area of epithelial defect, ulcer or abrasion takes *bright green* stain (Fig. 16-11).

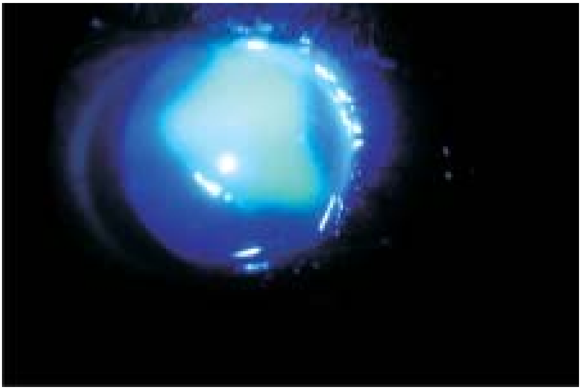


Fig. 16-11: Fluorescein staining of corneal abrasion

Rose Bengal

- It is a fluorescein derivative dye and it stains mucus, dead and devitalised cells bright red.
- It does not stain epithelial defect.

- The technique is same as fluorescein staining except cobalt blue filter is not required.
- Application of Rose Bengal is associated with *stinging sensation* and is aggravated in patients with dry eye.
- It stains typically interpalpebral bulbar conjunctiva in two triangular areas on either side of the cornea with their apices towards the canthi in patients with Bitot's spot or dry eye (Fig. 16-12).

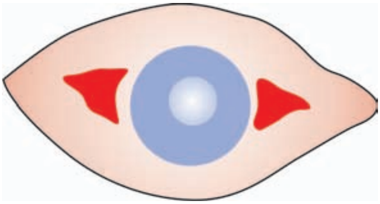


Fig. 16-12: Rose Bengal staining of bulbar conjunctiva

Lissamine Green

- It is an alternative to the Rose Bengal dye and *does not sting*.
- The technique is same as Rose Bengal staining.
- It's staining property is similar to that of Rose Bengal except the staining colour, which is *blue-green* (Fig. 16-13).
- It is well visible over the scleral surface. However, it is poorly visible over the dark iris due to lack of contrast.
- *The examination should be done quickly after the staining, since the dyes effect disappear rapidly*.

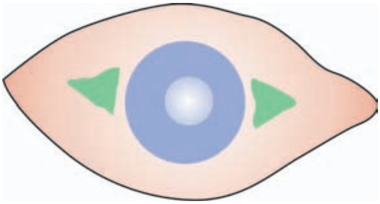


Fig. 16-13: Lissamine green staining of bulbar conjunctiva

TONOMETRY

Tonometry is the measurement of intraocular pressure. Accurate tonometry is essential for determining the course of management of glaucoma. Tonometer, the instrument used for tonometry, basically rely on deforming a specific area of the cornea by application of force which either flattens (applanates) or indents the cornea. So, the tonometers can be divided into two principal types, i.e. applanation and indentation.

INDENTATION TONOMETRY

Schiötz Tonometer is the classic example of indentation tonometer which was introduced in 1905. It is still used widely.

Principle–A plunger attached to the tonometer will indent soft eye more than hard eye. The amount of indentation of the cornea by the plunger is proportionate to the intraocular pressure. The Schiötz Tonometer weighs 16.5 gm with a base weight of 5.5 gm attached to the plunger. The base weight may be increased to 7.5 gm, 10 gm or 15 gm for higher intraocular pressure by addition of specifically marked weights (7.5/10/15) present in the tonometer set assembly (Fig. 16-14).

Parts of a Schiötz Tonometer (Fig.16-14).

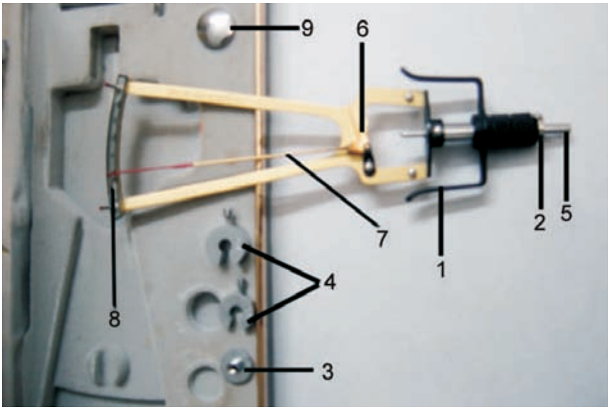


Fig. 16-14: Parts of a Schiötz Tonometer. 1 = Handle, 2 = Footplate, 3 = 5.5 gm weight, 4 = 7.5 gm and 10 gm weight, 5 = Plunger, 6 = Bent lever, 7 = Pointer, 8 = Scale and 9 = Test block (dummy cornea)

Technique

- The patient must be in recumbent position, i.e. lying flat on his back on an examination table.
- Anaesthetise the cornea topically preferably with proparacaine HCl (0.5%) or lignocaine HCl (4%).
- Ask the patient to look up at the ceiling. Free movement of the plunger in the shaft is tested by placing the footplate on the dummy cornea. The pointer will show reading of "0" at the scale.
- Place the sterilised footplate of the tonometer vertically gently on the central part of the cornea to evenly indent the cornea. The eyelids should be retracted firmly by fingers to prevent pressure on the eyeball.
- Free vertical movement of the plunger determines the scale reading. Reliable reading can only be read off from the scale when the pointer shows a pulse.
- Conversion table 1955 prepared by *Friedenwald, Kronfeld, Ballantine and Trotter* is used for estimation of intraocular pressure into mm of Hg (Schiötz). This conversion table is supplied with each Schiötz Tonometer.
- Scale reading between 2 and 6 is usually considered. If initially the scale reading is below 2, then 7.5 gm weight is added and the tonometry process is repeated. Ideally two readings using two different weight is employed, to detect also any abnormality of ocular rigidity. In eyes with abnormal scleral rigidity, there will be a discrepancy between the two readings. Then, the IOP value is corrected by consulting *Friedenwald's nomogram*.
- The IOP values obtained from the conversion table 1955 with 5.5 gm, 7.5 gm and 10 gm weights should not differ from each other by more than 3 mm of Hg in the same eye. If it occurs then the rigidity of the eyeball is abnormal. In patients with abnormal rigidity of the eyeball the IOP measurement with the 5.5 gm weight approximates to the actual intraocular pressure.
- *Apply 1–2 drops of antibiotic eye preparation to the eyes immediately after completion of the procedure.*

Advantages

- Easy to use
- Economical
- Portable
- Does not require a slit-lamp.

Disadvantages

- It may show a false low IOP reading in eyes with low scleral rigidity such as high myopia, after retinal detachment surgery, vitreoretinal surgery and strong miotic therapy.
- Similarly, it may show a false high IOP reading in eyes with high scleral rigidity such as microphthalmos, high hypermetropia, nanophthalmos, etc.

Care and Maintenance

- Remove the 5.5 gm weight from the plunger by unscrewing.
- Withdraw the plunger and clean it by wiping with isopropyl alcohol (70%) swab.
- Clean the footplate cavity with 70% alcohol soaked stick (supplied with the tonometer) and leave the tonometer to dry.
- Always keep the tonometer in a closed case (supplied by the manufacturer).
- Always sterilise the footplate and the lower end of the plunger before the procedure to avoid cross infection and ulceration, if the corneal epithelium gets abraded by the tonometer.

Sterilisation

Flaming the footplate and the lower end of the plunger in spirit lamp for 10 seconds or wiping with isopropyl alcohol (70%) swab.

APPLANATION TONOMETRY

It is based on the Imbert-Fick law which states that for an ideal, thin-walled sphere, the pressure inside the sphere (p) is equal to the force necessary to flatten it's surface (W) divided by the area flattened (A). So, $p = W/A$. However, human eye is not an ideal sphere due to variable thickness of the cornea and sclera, i.e. thickness of globe is not uniform.

In applanation tonometry very small area (3.06 mm in dia) is applanated. Therefore, the amount of force needed is equal to the IOP. The capillary attraction of the tear meniscus negates the rigidity of the cornea. So, the IOP reading is not affected by variations in the scleral rigidity.

Goldmann applanation tonometer was introduced in 1954 and is still considered the "gold standard" of tonometry, i.e. most accurate. It consists of a double prism with a diameter of 3.06 mm, in the centre of a cone-shaped head (Fig. 16-15). The double prism converts the circular tear meniscus into two semicircles.

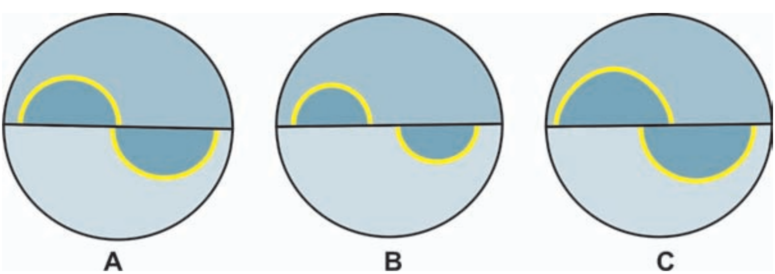
Fig. 16-15: Goldmann applanation tonometer

Technique

- Sterilise the prism by wiping with a isopropyl alcohol 70% swab and allow it to dry.
- Instill one drop of topical anaesthetic [proparacaine HCl (0.5%) or lignocaine HCl (4%)] into the conjunctival sac.
- The patient is positioned comfortably at the slit-lamp in a dark room with the forehead and the chinrest against the headrest and chinrest respectively. He is asked to look straight ahead.
- The tearfilm is stained with fluorescein strip and excess of fluorescein is wiped away with tissue paper.
- Bright beam of light is projected obliquely (90°) through the cobalt blue filter at the prism. *In patients with high astigmatism, the red line on the tonometer prism mount should be aligned to the*

axis of the minus/concave cylinder. The Goldmann applanation tonometer prism mount has one white line mark at 180° axis for routine use and one red line mark at 43° to the horizontal axis.

- Preset the IOP dial between 1 and 2.
- Slowly advance the slit-lamp forward with the joystick until the prism touches the apex of the cornea. This is aided by retracting the upper and the lower lids and holding them against the orbital rim.
- The examiner observes a split image of the tearfilm meniscus, i.e. 2 yellow semicircles.
- Rotate the graduated dial on the side of the tonometer, until the inner edges of the 2 yellow semicircles just overlap (Fig. 16-16A).
- IOP reading (in mm of Hg)–Multiply the reading on the graduated dial by 10.
- Fluorescein staining should be optimum. Excess of fluorescein makes the semicircles too thick and small (Fig. 16-16B). Whereas, insufficient fluorescein makes them too thin and large (Fig. 16-16C).
- *The examiner should avoid exerting pressure on the globe while retracting the eyelids*.
- Calibration of the applanation tonometer at intervals of 6 months should be carried out to avoid inaccuracy of IOP readings.



Figs 16-16A to C: (A) Applanation area is correct and the dial reading = the IOP, (B) Excess fluorescein/dial reading < the IOP and (C) Insufficient fluorescein/ dial reading > the IOP

PERKINS HANDHELD TONOMETER

This applanation tonometer is handheld and is based on the principle of Goldmann applanation tonometer.

Technique

- Similar to Goldmann applanation tonometer.
- A graduated dial with the similar measurement is rotated to alter corneal applanation force.

Advantages

- It is portable and battery operated.
- It does not require a slit-lamp for the light source.
- It can be used in both recumbent and sitting posture.
- It is particularly suitable for bed-ridden patients, infants and children.

NEWER SPECIAL TONOMETERS

Mackay-Marg Tonometer

It is an electronic tonometer. A plunger, in the centre of a flat footplate which is used to applanate the cornea, protrudes by a negligible distance (5 μm). The counterforce required to resist displacement of this plunger, when the cornea is flattened by the footplate is related to the IOP. The reading is interpreted from a graph. It can be used in *scarred cornea*.

Noncontact Tonometer/Pneumotonometer/Air-puff Tonometer

These tonometers send a puff of air of sufficient strength to applanate, i.e. flatten a predetermined area of the central cornea. The time interval between the onset of puff of air to the applanation of the cornea is proportional to the IOP. A digital printout of the IOP in mm of Hg is available. It is based on the Goldmann applanation principle. Advantages are ; (1) it is devoid of any contact between the instrument and the eye, (2) topical anaesthesia is not required and (3) it can be used to measure IOP in both sitting and recumbent position.

Tonopen

It works on the same principle as the Mackay-Marg tonometer. It is a handheld, portable and battery operated tonometer. It is very small and light. Tonopen reading correlates well with the Goldmann tonometer. However, it slightly overestimates low IPO's and underestimates high IOP's. *It is possible to measure IOP by this Tonopen through bandage contact lens, oedematous cornea and irregular cornea*. It is possible to measure IOP in both supine and sitting position. It is particularly useful in infants and bed-ridden patients.

GONIOSCOPY

The term "gonioscopy" was coined by Alexio Trantas (1907). Gonioscopy is the visualisation of the structures of the angle of the anterior chamber with a magnification of 15 to 20 times. Usually, it is not possible to see these structures directly through the cornea because light rays from the angle of the anterior chamber undergo total internal reflection. Gonioscopy lens eliminates total internal reflection by replacing "cornea-air interface" by a "lens–air interface" at a different angle. Hence, it becomes possible to view the angle structures. It is wise and useful to be familiar with the angle structures (Fig. 16-17) and their identification points before practising the technique.

IDENTIFICATION OF THE ANTERIOR CHAMBER ANGLE STRUCTURES (FROM ANTERIOR TO POSTERIOR)

Schwalbe's Line

- It marks the anterior limit of the angle of the anterior chamber (AC). It is the termination of Descemet's membrane.
- *It marks the apex of the wedge of reflections from the anterior and posterior surface of the cornea from well-focussed thin slit beam (See Fig. 16-18)*.
- Schwalbe's line produces a bump on the endothelial surface. At 6'o clock location the bump collects pigments to form an irregular line of dotted pigment (Sampaoelesi's line). It is usually not apparent in young individuals. However, it becomes increasingly apparent as age increases.
- It appears as solid glistening translucent structure.

Trabecular Meshwork (TM)

- It has a soft velvety appearance which contributes to it's identification even in the absence of pigmentation.
- It is most easily identified at 12'o clock position since the typical pigmentation (Sampaoelesi's line) which collects at the Schwalbe's line inferiorly does not create any confusion.
- Anterior 1/3rd of the TM is nonfiltering and is usually devoid of visible pigmentation.
- Usually Schlemm's canal is not visible during gonioscopy. Schlemm's canal will be visible only when it is filled up with blood. Then it becomes visible behind the anterior non-pigmented 1/3rd of the TM.

Scleral Spur (SS)

- It is a narrow, solid, translucent and whitish band.
- Width of this band is ½ of the TM.
- It is most easily identifiable at 12'o clock position where it is least likely to be covered with pigments.

Iris Processes

- These are prominent in young people and decrease with advancing age.
- They should be differentiated from peripheral anterior synechias (PAS) when present. PAS simulates tiny volcanoes, some with the apices missing and others with the apices in place. PAS of inflammatory origin are prominent inferiorly whereas PAS developed from angle closure glaucoma are prominent at superior angles.

Ciliary Body (CB)

- Width of the ciliary body is same as the width of the trabecular meshwork (TM).
- If the width of the ciliary body band is wider than the TM band, then a suspicion of angle recession should be considered.

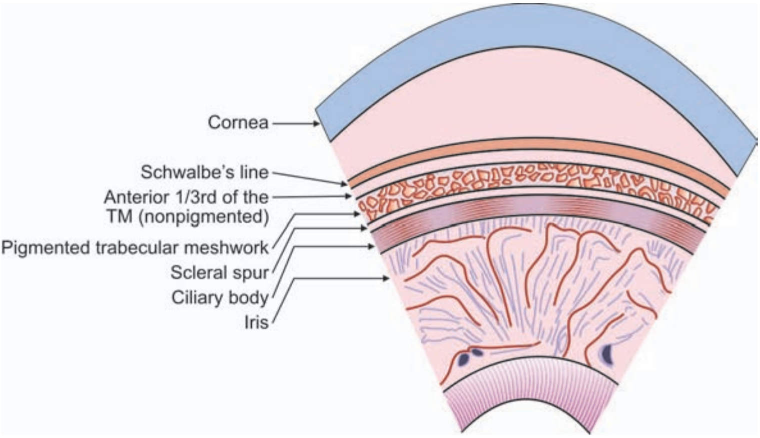


Fig. 16-17: Structures at the angle of the anterior chamber

DIRECT GONIOSCOPY

It is the direct viewing of the angle structures and is used for both diagnostic and operative procedures. The procedure is carried out in conjunction with a handheld microscope and a separate light source held in the other hand. The patient needs to be in supine position. The orientation of the angle structures is very simple. However, it is more difficult procedure. Examples of direct gonio lenses are; Koeppe, Barkan, Swan-Jacob and Thorpe. They are useful for examination in children, patient's with nystagmus and particularly under sedation or anaesthesia. They offer panoramic, wide view of the angle structures for comparison between different quadrants. It is suitable for surgical procedures, e.g. goniotomy.

Indirect Gonioscopy

It offers a mirror image view of the opposite angle structures. It is used for both diagnostic and laser procedures. Examples of indirect gonio lenses are; Goldmann 3-Mirror/2-Mirror/1-Mirror gonio lens, Zeiss 4-Mirror gonio lens and Posner 4-Mirror gonio lens.

Technique of Goldmann's Gonioscopy

- Explain the painless nature of the procedure to the patient and assure him to obtain maximum cooperation from him.

- Instill one drop of topical anaesthetic (proparacaine HCl 0.5% or lignocaine HCl 4%) into the lower fornix of both eyes.
- Ask him to keep his eyes open. Place his chin and forehead firmly against respective rests.
- Fill half of the cup of the lens with coupling liquid (K-Y jelly, methylcellulose 2% or carboxymethyl cellulose 10%). Hold the lens in your dominant hand and ask the patient to look up. However, some newer 3-Mirror models are designed which require only normal tearfilm as the fluid interface.
- Retract upper lid of the patient firmly against the superior orbital rim with the other hand. Use ring finger of the dominant hand to retract the lower lid. Place the lower rim of the lens into the lower fornix and then position the lens quickly and gently against the cornea to avoid spilling of the coupling fluid. Ask the patient to look straight.
- During observation of the angle structures of the right eye, hold the lens in your left hand and *vice versa*. It is convenient to use an elbow rest on the slit-lamp table. Index finger of the hand holding the lens may be used to support on the patient's upper eyelid.
- The incident light beam should be perpendicular to the mirror.
- After completion of gonioscopy the suction seal is broken by applying gentle pressure under the lower lid.

Standard Technique of Visualisation of Angle Structures

- While using the Goldmann 3-Mirror, use the *dome-shaped mirror* to view angle structures.
- *Start with the mirror at 12'o clock position to visualise the 6'o clock, i.e. inferior angle.* Sweep your gaze up from the pupillary margin to the angle recess and try to identify the angle structures particularly the velvety and pigmented trabecular meshwork. Then, set your gaze on the Schwalbe's line. Note whether Sampaoelesi's line is present or not.
- Now with your eyes focussed on the Schwalbe's line, the gonioscopy lens is rotated clockwise so that your view moves from 6'o clock to 12'o clock through 9'o clock, never loosing sight of the Schwalbe's line. As the mirror is rotated, the

pigments on the Schwalbe's line should become less visible and conspicuous. Usually the pigmentation completely disappears near 9'o clock.

- Shift your focus to pigmented trabecular meshwork (identified by it's velvety texture) as the new landmark, as the mirror is rotated clockwise. The degree of pigmentation in TM is more or less equal in all quadrants with the exception of 3 and 9'o clock, where it is slightly less.
- There is another easy way of identifying Schwalbe's line. Schwalbe's line is the transition line between the corneal and scleral curvatures. If a thin slit of beam is aimed on the angle, it produces reflexes on both the anterior and posterior surfaces of the cornea. The reflection (p) on the inner side corresponds to the posterior surface of the cornea and is continuous with the reflection of the angle structures and anterior surface of the iris. The outer reflection (a) corresponds to anterior surface of the cornea and ends at the Schwalbe's line, where it joins with the inner (p) reflection (Fig. 16-18). Hence, Schwalbe's line is identified by *(i) end point of outer reflection; (ii) joining point of both the reflections and (iii) Sampaoelesi's line, if present*.
- If the patient is asked to look at the mirror, it becomes easier to view that particular angle under observation.

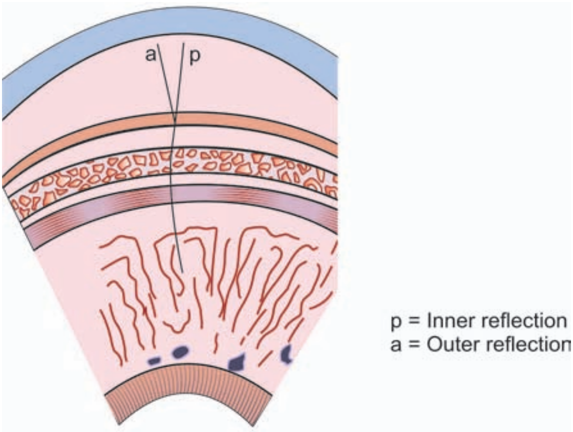


Fig. 16-18: Thin slit-lamp beam—Identification of Schwalbe's line

Technique of Zeiss 4-Mirror Gonioscopy

- The technique is quite similar with few exceptions.
- Coupling fluid is not required and the lens is simply touches the cornea after topical application of anaesthetic.
- The patient is asked to look straight at the fixation light.
- Achieve additional support by resting the hand holding the handle of the gonioscopy lens against patient's check.
- Indentation gonioscopy is not possible with the Goldmann 3-Mirror gonioscopy lens. In this technique, Zeiss gonioscopy lens is gently pressed against the cornea. This is performed to distinguish angle closure between appositional and synechial. This manoeuvre will force aqueous humour into the periphery of anterior chamber. The interpretation is based on the following findings:
  - i. Synechial angle closure–It will remain closed even on indentation.
  - ii. Appositional angle closure–Previously hidden angle structure, e.g. trabecular meshwork will become visible on indentation.
- Zeiss lens has 4 identical mirrors. So, 4 quadrants are examined without rotation of the lens. The little areas in between the mirrors can be visualised by turning through the lens only few degrees (approx. 8°–12°).

DIFFERENT WAYS OF GRADING OF ANTERIOR CHAMBER DEPTH AND ANGLE OF THE ANTERIOR CHAMBER

Van Herick-Shaffer Technique

It is used for estimation of depth of the angle. The patient is seated in a slit-lamp. The thinnest slit beam is used to illuminate cornea perpendicularly near temporal limbus. The optical section thus created is viewed at 60° from the light source. Ratio between AC depth (cornea-iris distance visible as dark shadow) and corneal thickness (width of the optical section of cornea) is noted (Fig. 16-19).

- Grade 0 (closed): There is no black shadow, i.e. iris is in contact with the corneal endothelium.
- Grade I: AC depth is less than 25% of corneal thickness.

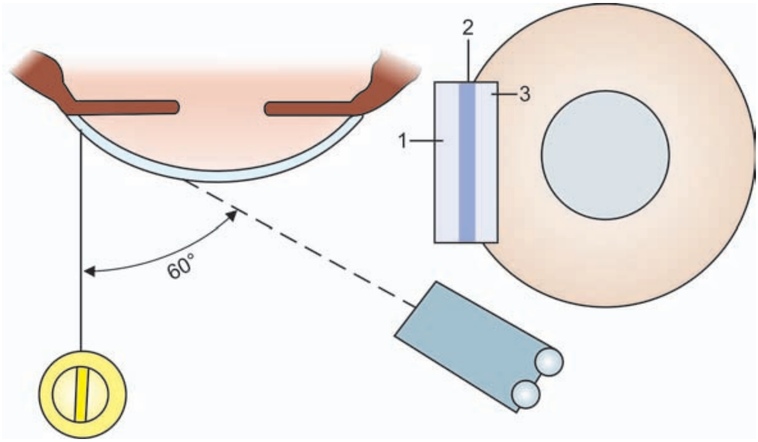


Fig. 16-19: Van Herick – Shaffer technique of grading 1= Corneal thickness, 2= AC depth and 3= Illumination iris surface

- Grade II: AC depth is 25% of corneal thickness.
- Grade III: AC depth is 25–50% of corneal thickness.
- Grade IV: AC depth is more than 50% of corneal thickness.

Shaffer's Grading

It is used to estimate the angle in degrees between anterior iris surface and trabecular meshwork Schwalbe's line (Table 16-1 and Fig. 16-20).

Table 16-1: Shaffer's grading

Grade	*Angle in degrees*	*Visibility of anatomical structures*	*Clinical significance*
Grade IV	45°	All angle structures including ciliary body is visible	Angle closure is not possible
Grade III	25–35°	Open angle, at least Scleral spur is easily visible	Angle closure is not possible
Grade II low	20°	Only TM is easily identified	Angle closure risk is
Grade I	10°	Only Schwalbe's line and occasionally anterior non-pigmented TM is identified	Angle closure risk is high
Slit	< 10°	No single angle structure is visible but iridocorneal contact is absent	Angle closure risk is imminent
Grade 0	0°	Iridocorneal contact is visible	Closed angle

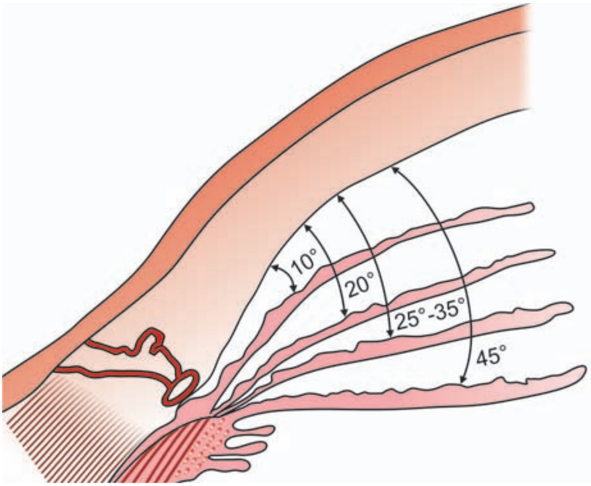


Fig. 16-20: Shaffer's grading (IV-0) and angles subtended between anterior iris surface and TM Schwalbe's line

Spaeth's Grading

This is a comprehensive and elaborate grading introduced by George L Spaeth taking into account four variable parameters.

- IRIS INSERTION–LOCATION
  A = Anterior to Schwalbe's line
  B = Behind Schwalbe's line
  C = Scleral spur
  D = Deep–Ciliary body is visible
  E = Extremely deep–Large part of the ciliary body is visible.
- ANGLE OF THE ANTERIOR CHAMBER IN DEGREES *between the line tangential to the inner surface of the TM and the anterior iris surface at 1/3rd distance from the iris root*.
- Curvature of the iris
  b = Bowing anteriorly
  p = Plateau configuration
  f = Flat
  c = Concave, i.e. bowing posteriorly
- PIGMENTATION OF TM
  0 = Nil or absent

+1 = Just appreciable
+2 = Mild
+3 = Marked
+4 = Intense

INDIRECT BIOMICROSCOPY

It is the evaluation of the posterior segment by slit-lamp biomicroscope in conjunction with accessory (auxiliary) lenses. These lenses are of either noncontact or contact type (Table 16-2).

Table 16-2: Indirect biomicroscopy (auxiliary) lenses

Noncontact	*Contact*
Concave–Hruby lens (–58.60D)	Goldmann 3-Mirror (central lens = –64D
Convex – +60D lens (El Bayadi), +78D lens and +90D lens	

HRUBY LENS

It is planoconcave lens of –58.60D strength. It is used to examine the fundus and the posterior vitreous. It is mounted on the slit-lamp by a holder and is of noncontact variety. Image magnification is low. The magnification (16X) is equal to that of direct ophthalmoscope. However, image magnification is determined by magnification of the slit-lamp. The field of view of the posterior pole is comparable to the field observed in direct ophthalmoscopy. The

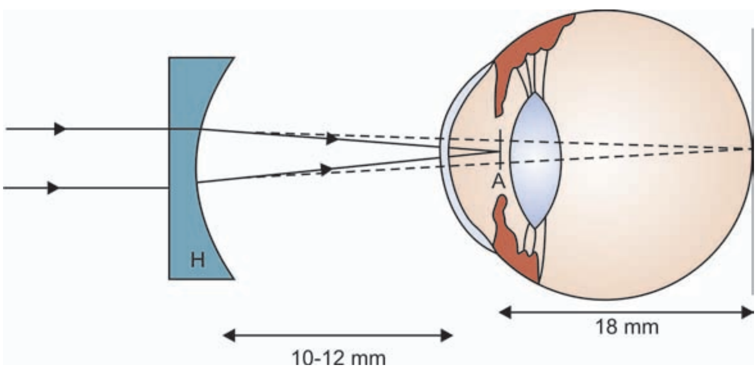


Fig. 16-21: Hruby lens—Optical principle
H = Hruby lens, A = Image of fundus appears in plane A

image is erect, virtual, binocular and stereoscopic, i.e. 3-dimensional (Fig. 16-21). It is located 18 mm in front of the retina, if the Hruby lens is positioned 10–12 mm in front of the cornea (Table 16-3 and Fig. 16.21). *The concave surface of the lens should face the cornea*.

GOLDMANN 3-MIRROR LENS

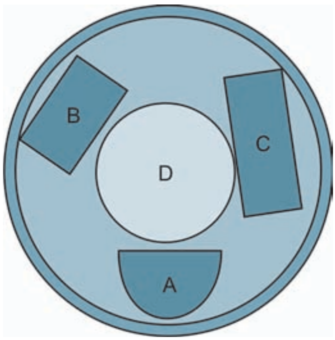


Fig. 16-22: Goldmann 3-Mirror Lens with functions of different mirrors

Mirror A (59°) dome-shaped = Gonioscopy, to view pars plana and extreme retinal periphery
Mirror B (67°) square-shaped = To view retina from equator to periphery, i.e. ora serrata
Mirror C (73°) large- and oblong-shaped = To view retina from equator to outer periphery of 30° of posterior pole of retina
Mirror D (- 64.00D) central = To view central 30° of the posterior pole of retina.

Technique

- Pupil should be maximally dilated with instillation of tropicamide 1% and phenylephrine HCl 5%.
- Insertion technique is discussed in details in Goldmann 3-Mirror gonioscopy.
- However, the use of the 2-Mirrors angled at 67° and 73° (Fig. 16-22) for peripheral retinal examination needs elaborate discussion. *The image is simply inverted but lateral orientation is not reversed*. The retinal area facing the mirror is viewed.

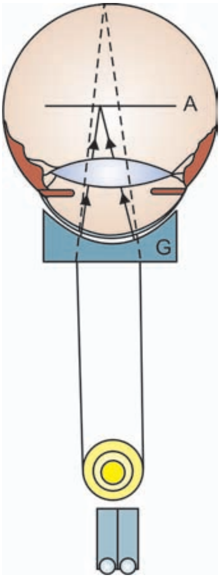


Fig. 16-23: Goldmann 3-Mirror indirect biomicroscopy—Optical principle. G = Goldmann 3-Mirror lens (central), A = Image of fundus appears in plane A

- Examine the vitreous cavity with the central contact lens—Use both vertical and horizontal slit beam.
- Examine the central 30° of posterior pole of retina with the central lens D (Figs 16-22 and 16-23). The central (D) mirror/ contact lens gives a *direct, erect, virtual and stereoscopic image* of the posterior pole of the retina and the image is located in midvitreous.
- Visualise the rest of the retina by rotating the lens through 360°. While viewing the different areas of retina rotate the axis of the incident light beam of the slit lamp in a way so that it is always at right angle to the mirror. Use the equatorial mirror C (73°) first and then the peripheral mirror B (67°).
- More peripheral view of the retina is obtained by tilting the lens to the opposite side and by asking the patient to move his eyes to the same side.

+90D, +78D AND +60D LENS (BIO)

The technique of fundus examination by these lenses is termed *biomicroscopic indirect ophthalmoscopy* (BIO). These are noncontact fundus lenses. The fundus image is *magnified and stereoscopic*. However, the fundus *image is inverted and laterally reversed* (Fig.16-24). The +60D (El Bayadi) lens provides more magnification but smaller field of view (Table 16-3). It is particularly suitable for minute examination of the optic disc and the macula. The +90D lens provides lower magnification but larger field of view (Table 16-3) and is particularly suitable in undilated or poorly dilated pupil. It is possible to examine the retina upto equator through these lenses.

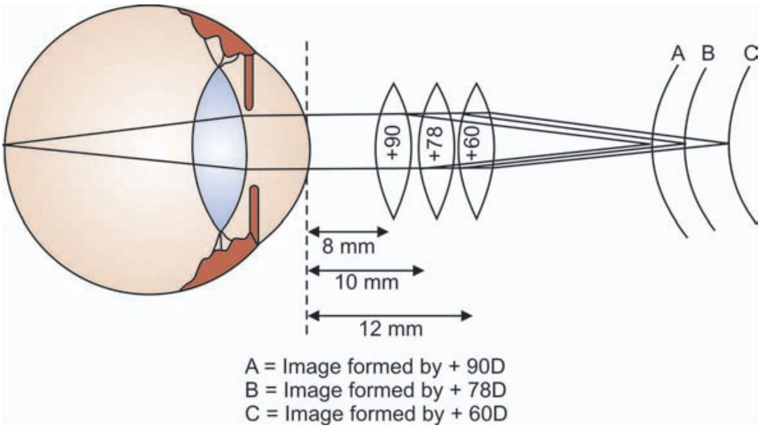


Fig. 16-24: BIO lenses—Optical principles

Technique of BIO

- Dilatation of pupil–However, it is possible to view central posterior pole of the retina of 2–3 disc diameter in an undilated pupil.
- Comfortable seating of the patient in the slit-lamp with his/her forehead and chin against headrest and chinrest. He is asked to look straight ahead.
- Adjust the slit-lamp–Set the PD (pupillary distance) and focus accurately. Adjust the incident light beam of the slit-lamp to about ¼th of it's full circular diameter. Set the illumination source in line with the viewing system, i.e. coaxial. Set the light intensity at the lowest using the rheostat. Set the magnification at it's lowest setting, e.g. 8X.

Table 16-3 : Comparison of features of various lenses used for biomicroscopic indirect ophthalmoscopy (BIO)

Criteria	*Hruby Lens*	*Goldmann*	*+90.00D*	*+78.00D*	*+60.00D*
Corneal contact	No	Yes	No	No	No
Power in diopter	– 58.60	– 64.00	+ 90.00	+78.00	+60.00
Magnification	16X	0.93 X Magnification of S/L*	0.75 X Magnification of S/L*	0.9 X Magnification of S/L*	1 X Magnification of S/L*
Field of view	8°	30°	90°	80°	60 °
Location of image	Within the eye, 18 mm in front of the retina, erect and virtual	Within the eye, in the mid vitreous, erect and virtual	In front of the +90D lens, real and inverted, laterally reversed	In front of the +78D lens, real and inverted, laterally reversed	In front of the +60D lens, real and inverted, laterally reversed
Working distance of the BIO lens from the cornea	10-12 mm anterior to the cornea	In close contact with the cornea	7–8 mm anterior to the cornea	9–10 mm anterior to the cornea	11–12 mm anterior to the cornea

*S/L = Slit-lamp biomicroscope

- Focus on the cornea with the light beam passing through the pupillary centre.
- Hold the +90D lens between thumb and index finger with it's back surface (often distinguished by a white ring) about *8 mm in front of the patient's cornea*, just clearing the eyelashes with the light beam passing through its centre. The examiner can use elbow rest or rest his fingers on the forehead rest for comfortable holding of the lens.
- *While looking through the oculars and holding the +90D lens, pull the slit-lamp about 1 inch towards you with the joystick until the real, inverted and aerial fundus view comes into sharp focus*.
- Scanning of posterior pole–instead of moving the condensing lens (as done in indirect ophthalmoscopy), operate the joystick to move the slit-lamp left and right as well as up and down.
- Reduce reflections by slight tilting of the light source (5°–10°).
- Increase the width of the light beam and magnification for larger field of view and minute details respectively.
- In order to examine the vitreous slowly move the slit-lamp further towards you.
- Peripheral retinal viewing–Ask the patient to look up or down, or to the left or right. Realign the light beam with the repositioned pupil. Hold the +90D lens in usual position. Sharply focus the fundus image by moving the slit-lamp forward or backward.
- Magnification—16X magnification provides good detail as well as wide field of view of retina. However, higher magnifications may be used for very minute details.

LENS MEASURE (OR GENEVA LENS MEASURE)

It is an instrument used to determine the surface power of a lens by measuring the radius of curvature of a spherical or cylindrical curve. The addition of the surface powers equals the power of the lens. The instrument looks like a pocket-watch consisting of a pointed mobile prong placed in between two fixed pointed prongs attached to the edge (Fig. 16-25). Linear displacement of the central one is reflected in the calibrated dial of the measure. The instrument is calibrated for lenses made of crown glass (R.I. = 1.523) to give a reading in diopters. However, for lenses made of other materials of different refractive indices the true surface power in diopters can be calculated from the following formula;

$$F_T = \frac{n-1}{0.523} \times F_{LM}$$

F_T = True surface power in diopters

n = Refractive index of the lens

F_{LM} = Reading in diopters on the lens measure.

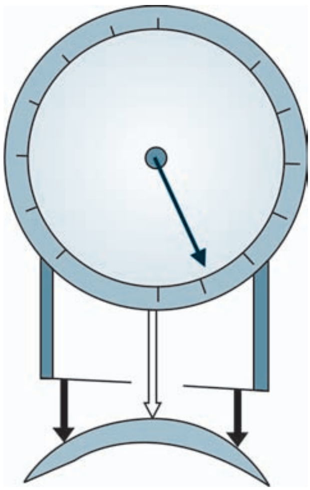
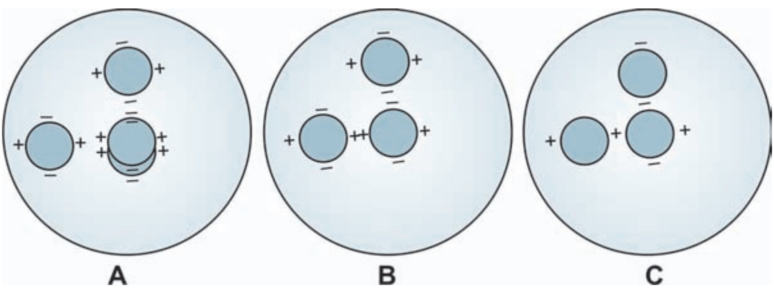


Fig. 16-25: Geneva lens measure

KERATOMETER (OR OPHTHALMOMETER)

Cornea acts as a convex mirror. So, an illuminated object called "mire", when placed in front of the cornea produces a virtual, erect and smaller image of the mire behind the cornea. The size of the object, i.e. "mire" varies with the curvature of the cornea. Based on this principle, radius of curvature of cornea is measured at 2 points (1.25 mm on either side of it's centre in Javal & Schiötz keratometer and 3–3.2 mm on either side of it's centre in Bausch & Lomb keratometer). The Bausch & Lomb keratometer design is most widely used. In Bausch & Lomb keratometer the size of the "mire" is fixed but the amount of doubling varies. The mire consists of a circle with a horizontal pair of plus (+) signs and vertical pair of minus (–) signs marking outside the circle. The image of the mire is observed through a telescope. Two pair of holes oriented horizontally and vertically in an otherwise opaque diaphragm between the objective lens and the doubling prism, assist in the focussing. The observer looks through the eyepiece, after proper alignment at the patient's cornea. The view before focussing is shown in Figure 16-26A. The observer rotates the focusing knob to change the distance between the objective lens and the patient's cornea until the lower right image of the mires superimpose, i.e. the overlapping of images disappear (Fig. 16-26B). The observer now rotates another knob to move the doubling prism to superimpose the plus (+) signs in between the two lower mires and the minus (–) signs in between the upper and lower mire (Fig. 16-26C). The dioptric power of the cornea in both meridians are obtained from the scale on the focussing knobs.



Figs 16.26A to C: (A) B & L keratometer—the mires before focussing, (B) B & L keratometer—fusing of mires (lower right), (C) B & L keratometer—fusing of + signs between two lower mires and - signs between upper and lower right mire

The Bausch & Lomb keratometer measures both horizontal and vertical meridian simultaneously and conveniently in one position without rotating the instrument. Hence, keratometers designed like the Bausch & Lomb are termed "one–position" keratometer. However, "two–position" keratometers such as Javal & Schiötz and Haag–Streit models must be rotated to measure each meridian separately. So, chance of detection of irregular astigmatism is more common with the "two–position" keratometers. Autorefractometers with built-in keratometers are now becoming increasingly available. They provide fast measurements alongwith easy mode of operation.

USES OF KERATOMETER

- Contact lens practice and specially fitting of rigid (corneal) contact lens.
- Assessment of corneal power.
- Calculation of intraocular lens (IOL) power.

LENSOMETER (OR FOCIMETER)

The lensometer is an instrument used to measure the vertex power of a lens, the power and axis of a cylindrical lens and the power of a prism. Lensometer is also used to measure the refractive power of a contact lens.

PARTS OF LENSOMETER (FIG. 16-27)

A lensometer comprises of a focussing system and an observation system. The observation system consists of a viewing telescope with an adjustable eyepiece. The eyepiece is supplied with a rotatable cross line graticule and a protractor scale to measure the axes of cylindrical lenses and power of the prism. The focussing system

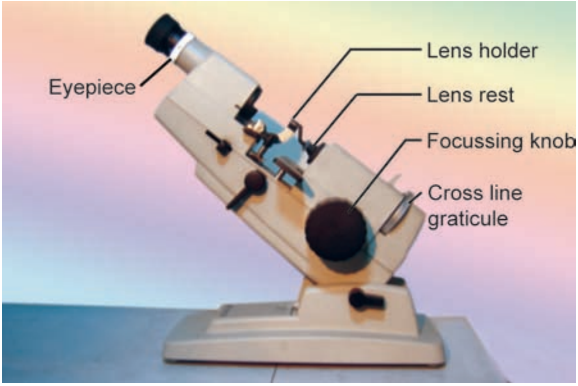


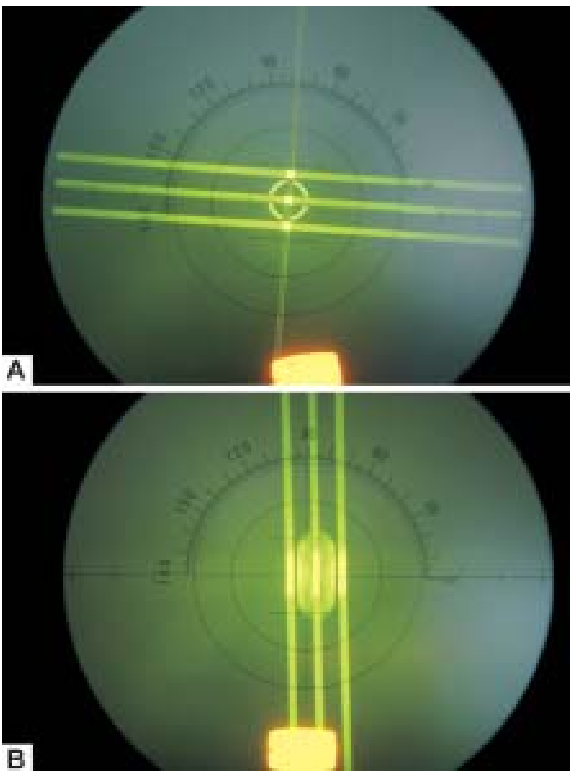
Fig. 16-27: Lensometer—Eyepiece design

consists of an illuminated target and a collimating lens. The function of the collimating lens is to change the path of the light rays to parallel. The target is a ring of dots formed by a disc with punched circle of holes. The measuring scale (in diopters) is either on the focussing knob or attached to the target and viewed through a magnifying device.

PROCEDURES

- The instrument is turned on.
- The instrument setting is aligned to zero (0) marking on the focussing knob.
- The eyepiece is adjusted to focus the dots and the graticule sharply for the examiner's vision (in projection lensometers eyepiece adjustment is not required).
- The lens under test is mounted with the back surface against the lens rest and is secured with the lens holder. However, in bifocal lenses, the front vertex power of both the distance and near segment is measured. The difference in measurement between the two readings gives the value of bifocal addition.
- The knob is rotated, i.e. the target is moved towards or away from the collimating lens until the light entering the viewing telescope is parallel. This is indicated by focussed image of the target.
- The target is aligned to the centre of the eyepiece crossline graticule.
- If the lens under test is required to be moved for proper centration, always pull the lens holder up to avoid scratching of the lens surface.
- If the lens under test is spherical, the dots will form a ring (Fig. 16-28A). However, if the lens under test is cylindrical, the dots will form a series of lines (Fig.16-28B).
- The length of the lines is proportional to the difference between the two principal meridians, i.e the power of the cylindrical lens.
- In cylindrical lenses the target is focussed separately for the two principal meridians of greatest and least curvature. The cross line graticule is rotated so that it aligns to the target lines and the axis is obtained from the protractor scale.

- Interpretation of keratometer reading:
  1st reading = power of the sphere.
  2nd reading–1st reading = Power of the cylinder (Algebraic subtraction of 1st reading from 2nd reading, taking into account their sign).
  The axis of the 2nd reading = Axis of the cylinder.
- Contact lens practitioners use projection lensometer (supplied with lens stop) to measure power of the contact lenses. Contact lenses are placed on the lens stop to measure the front vertex power with the convex surface towards the stop. The concave surface is placed towards the stop to measure back vertex power.



Figs 16.28A and B: (A) Image of illuminated target forms ring of dots in spherical lenses and (B) Image of illuminated target forms a series of lines in cylindrical lenses

Manual lensometers are of two variety; eyepiece designs and projection designs. *In projection design several people can view the reading at a time and there is no need to adjust the eyepiece*. Eyepiece designs are cheaper and equally accurate if eyepiece adjustment is done properly. Calibration of lensometers by a calibration gauge should be carried out at regular intervals.

Automated lensometers are becoming increasingly available. They provide very quick, digital measurement display and print out with easy mode of operation.

DIRECT OPHTHALMOSCOPE

Direct ophthalmoscope is a portable, handheld, self-illuminated instrument used to view from the cornea to the retina upto the equator. It is powered by either disposable or rechargeable battery.

ADVANTAGES OVER INDIRECT OPHTHALMOSCOPY

- It is economic.
- Relatively easy to familiarise with the technique (shorter learning curve).
- The image is erect.
- Higher magnification (15X in emmetropic) offers finer clinical assessment of the macula, the optic nerve head and vessels of the retina.
- It is possible to examine the ocular structures right from the cornea upto the retina including intermediate ocular structures like the lens and the vitreous humour.

DISADVANTAGES OVER INDIRECT OPHTHALMOSCOPY

- It is a monocular procedure.
- It lacks depth perception, i.e. stereopsis.
- The field of view is restricted–field of view is only 8° compared to 40° in indirect ophthalmoscopy.
- It is not possible to examine the retina beyond the equator even in a maximally dilated pupil.

PROCEDURE

- Direct ophthalmoscopy is preferably done in dark room. The patient is asked to look at a distant target in front. Prior pupillary dilatation facilitates retinal view.
- The direct ophthalmoscope is held in hand in such a way that the index finger reaches effortlessly the "lens wheel" required for fine focussing. The direct ophthalmoscope is held in right hand for examining the right eye and *vice versa*.
- The clinician should stand on the right side of the patient for examining the right eye and *vice versa*.
- Conventionally right eye is examined first. Distant direct ophthalmoscopy is performed by focussing the ophthalmoscope light on the patient's pupil from a distance of half meter (approx.). The observation peephole should be positioned in front of the clinician's eye. The power of the "lens wheel" is set at +20.00D. The pupillary area will appear red due to retroillumination of the light from the choroidal blood vessels. This is called "red glow" or "red reflex". Any opacity in the pathway will appear dark against the "red reflex" background. The location of the opacity in the eye can be further determined by moving the ophthalmoscope in vertical axis. Opacities located behind the crystalline lens will move in the same direction of movement of the ophthalmoscope, whereas opacities located in front of the crystalline lens will move in the opposite direction.
- Now move close to the patient's eye just beyond the eyelashes of the patient. Various areas of the media can be viewed by focussing the "lens wheel" from +20.00D to +5.00D in emmetropic patient. In emmetropic patient, the retina will come in a sharp focus at "0" power of the "lens wheel".
- Dioptric power of the "lens wheel" required for sharp focus of the retina depends on the following factors:
  i. The clinician's refractive status
  ii. The patient's refractive status
  iii. The distance of the direct ophthalmoscope from the patient's cornea.

- The field of view in direct ophthalmoscopy depends on;
  i. The distance of the direct ophthalmoscope from the patient's cornea
  ii. The patient's refractive status.

  The field of view increases as the eye is approached. The field of view is more in hypermetropes and less in myopes.
- In direct ophthalmoscopy, it is essential to relax the accommodation of the clinician to view the fundus for longer period without any eyestrain. It helps the clinician to relax the accommodation by *keeping both the eyes open during the procedure*.
- It is helpful to steady the patient by placing the other hand of the clinician on the patient's head and gently elevating the upper eyelid with the thumb.
- While examining the posterior pole, first observe the optic disc, physiological cup and neuroretinal rim. Now shift your focus to the macula and the fovea. One practical help in finding the optic disc is tracing the blood vessels centripetally. Examine the different retinal quadrants from the opposite side and ask the patient look at the direction of the retinal quadrants.
- Different apertures and filters are incorporated in the direct ophthalmoscope for flexibility of retinal examination. The "circular wheel" for changing the apertures is located in the back of the direct ophthalmoscope head. The function of the different apertures and filters are listed below (Fig. 16-29);
  i. Microspot–It allows view of the fundus through a *small undilated pupil*. It projects a 1.5 mm diameter spot (1 disc diameter) of light on the retina in majority of eyes. Hence, it can be used to estimate the distance of a lesion on the retina from the optic disc or the macula. It further helps to estimate cup/disc ratio.
  ii. Medium aperture–It provides view of the fundus through an *undilated normal sized pupil*.
  iii. Large aperture–It is the *standard aperture* for general examination of the eye and retina in *dilated pupil*.
  iv. Fixation aperture/Star/Graticule–It is used to measure eccentric fixation in squint. It can be also used to measure distance of a lesion from the fovea. It can be conveniently used

to measure cup/disc ratio from the crossline graticule design in certain direct ophthalmoscopes.

v. Slit aperture–It is used to assess levels of lesions and tumours. It is also used to distinguish between macular hole and macular cyst.

vi. Cobalt blue filter–It is used after staining with fluorescein dye to observe corneal abrasions, punctate keratitis and lesions on the cornea.

vii. Red free filter (green)–It is used to improve contrast while viewing retinal blood vessels and haemorrhages. It is also used to differentiate between microaneurysms (dot) and deep haemorrhages (blot). It is also used to view nerve fibre layer defects of the retina in glaucoma.

viii. Polarising filters–Few direct ophthalmoscope are fitted with this filter to reduce glare during retinal examination.

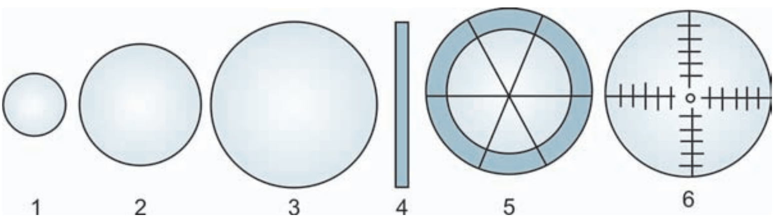


Fig. 16-29: Different apertures in direct ophthalmoscope. **1** = Microspot, **2** = Medium aperture, **3** = Large aperture, **4** = Slit aperture, **5** and **6** = Fixation aperture/Star/Graticule

CHAPTER

17

Low Vision and Low Visual Aid

INTRODUCTION

Low vision indicates significant visual handicap, which cannot be adequately corrected by refraction, medication or surgery, but at the same time presence of significant residual vision. WHO's working definition of low vision is as follows: "*A person with low vision is one who has impairment of visual functioning even after treatment, and or standard refractive correction, and has a visual acuity (VA) of less than 6/36 (or 20/120) to light perception, or visual field of less than 10° from the point of fixation, but who uses, or is potentially able to use vision for the planning and or execution of a task*."

In USA, legal blindness is defined as the presence of distant visual acuity in better eye of 6/60 (or 20/200) or less after conventional optical correction, and or a defect in the visual field in which the widest diameter of vision subtends an angle of less than 20°.

CLINICAL ASSESSMENT OF A PATIENT WITH LOW VISION

CASE HISTORY

It is very essential to meticulously check the case history. It includes the onset and the duration of the offending illness. It also includes assessment of financial, emotional, psychological and educational background of the patient.

VISUAL ACUITY

Residual usable visual acuity for both distance and near should be estimated. Since visual acuity for distance and near is invariably less than optimal, specialised charts, e.g. Bailey & Love, log MAR chart, etc. may be of immense help in particular situations. In paediatric age group and nonverbal patients Teller cards, Optokinetic drum, etc. may be used (discussed in detail in Chapter 18).

CONTRAST SENSITIVITY FUNCTION

Two persons with the same Snellen's chart visual acuity can visually function differently. This difference can be predicted with the contrast sensitivity testing. Contrast sensitivity measurement is useful in providing information regarding functional low vision. It can be also used to predict outcome with low visual aids for that particular patient.

VISUAL FIELD

Automated perimeter is extensively used for visual field testing. However, in patients with low vision, Amsler Grid test and confrontation method have a special requirement. Amsler Grid test is often suitable for testing central field of 10° around the fixation point for patients with low vision (Fig. 17-1). In patients with low vision, to assist fixation, the fixation point is marked with a **X**.

Amsler grid chart: The Amsler grid chart is devised by Prof Marc Amsler. It can provide for rapid detection of slight abnormalities in the central 20° of visual field which are not detectable by the usual methods of perimetry. There are different patterns on each chart (10 cm × 10 cm). The most commonly used chart (Fig. 17-1) consists of a white grid of 5 mm squares on a black background with a central white fixation point.

Procedure

- The procedure should be done before ophthalmoscopy and without instillation of eyedrops affecting pupillary size or accommodation.

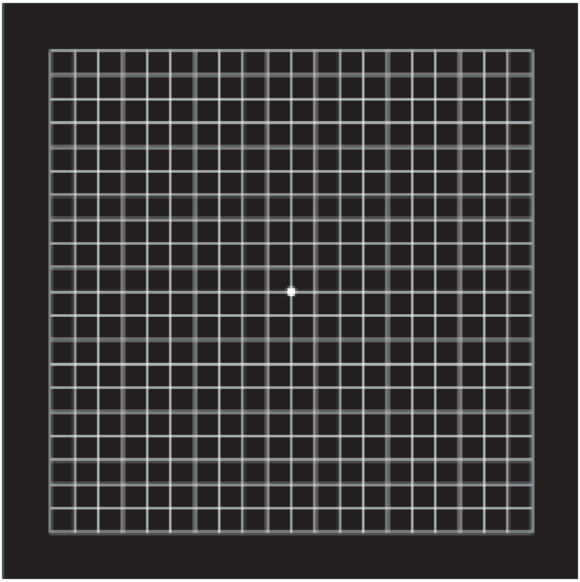


Fig. 17-1: Amsler Grid Chart

- The chart is to be viewed monocularly, in normal room illumination.
- Place the chart at normal reading distance (28–40 cm).
- The chart is to be viewed with the reading spectacles.
- During the entire procedure keep looking at the central fixation spot.
- A series of questions should be asked while the patient is looking at the central fixation point.
  1. Is the central spot visible? The absence of the spot may indicate the presence of a central scotoma.
  2. While viewing the central white spot can you see all four sides? The inability to perceive these areas may indicate the presence of an arcuate scotoma of glaucoma encroaching upon the central area or a centrocaecal scotoma.
  3. Do you see the entire grid intact? Is any area within the grid not visible? If an area of the grid is not visible, then a paracentral scotoma is present.

4. Are the horizontal and vertical lines straight and parallel? If not, then metamorphopsia is present. The parallel lines may "bend" inwards giving rise to micropsia or "bend" outwards giving rise to macropsia.
5. Do you see any blur or distortion in the grid? Any movement? A colour aberration? These changes may be present prior to the appearance of a definite scotoma.

COLOUR VISION TESTING

A majority of patients with low vision also suffer from colour blindness. Care should be taken to identify the type of colour deficiency. It helps in planning and designing training material and courses for such patients.

KERATOMETRY

It is performed to estimate corneal astigmatism objectively.

REFRACTION

Trial frame refraction should be performed with a retinoscope/ streak retinoscope (retinoscopy) often at a closer distance *(radical retinoscopy)*. In some situations autorefractometers may give an estimate of the refractive error. During subjective refraction, the examiner should employ large spherical power increments to elicit positive differential response. Usually, increment of 1.00D or 2.00D, instead of 0.25D increments is tried. Stenopaeic slit may be of immense help in locating the orientation of principal meridians at right angles to each other in correcting astigmatic error.

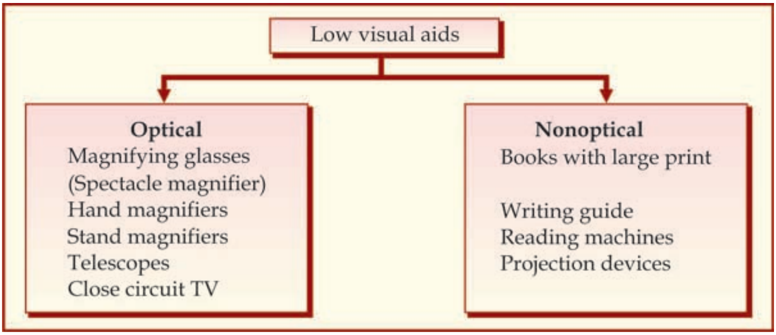
SLIT-LAMP EXAMINATION AND FUNDUS EXAMINATION

It often helps in diagnosing the aetiology of low vision.

MANAGEMENT OF PATIENTS WITH LOW VISION

The principle of management of low vision is based on efficient utilisation of residual vision to its fullest potential with the most appropriate low visual aid. However, it should be remembered that low visual aids do not cure the aetiology of low vision. This fact should be stressed upon while dispensing low visual aids.

Low visual aids may be classified as follows:



Each patient needs to be counseled individually and appropriate low visual aid to be prescribed according to his/her functional requirement for distance and near vision. The aim is to provide them with sufficient magnification to achieve their visual requirement. Low visual aids should be made available at affordable prices. A common complaint with low visual aids is that they work much better in the clinician's chamber than in the patient's home. The only possible explanation is that the illumination is much better in the clinician's low visual aid trial chamber.

WORKING PRINCIPLE OF LOW VISUAL AIDS

The aids, given to a person with low visual aid, work on the basic principle of providing them with sufficient magnification so as to achieve their visual goals. It must be stressed that magnification does not make the image any clearer but simply enlarges it. Thus a person with hazy vision or distorted irregular vision will still see hazy or distorted images but of a larger size. This larger image will allow him to fulfill his needs. This fact must be made clear to the user. Another point is to be noted is that field of vision decreases with magnification. Thus magnifiers must be adjusted to a position to get the clearest image and largest field of view. The importance of optimal lighting arrangements have to be stressed and patients educated about illumination while using these devices.

LOW VISUAL DEVICES

MAGNIFIERS

They are used for looking at objects at a close range. These are basically of two types, handheld devices and stand magnifiers.

Handheld devices are handheld magnifiers which are useful in reading signs, labels, prices and books. These may be easily carried into place of work, shops, etc. They are economical and available in a wide range of powers. They cannot be used by older patient with senile tremors, parkinsonism, etc. Also, one hand is occupied while using these.

Stand magnifiers are used to magnify pictures, newspapers, etc. It consists of a magnifier fixed on a stand resting flat on the material to be magnified. They have a fixed distance and are easy to use. However, they tend to lead to fatigue due to the posture of the user.

Optics of Magnifiers

Magnification by a convex lens is obtained by placing the object (AB) within the first principal focus (F_1) of the convex lens. An erect, virtual and magnified image (A_1B_1) is formed (Fig. 17-2) on the side of the object (AB) and behind it. The virtual image becomes larger and is situated further from the eye as the object approaches the first principal focus. Magnification is derived from the formula (M = F/4). Hence, image magnification by a +10.00D lens is M = 10/4 = 2.5 (M = Magnification, F = Power of the lens in diopter).

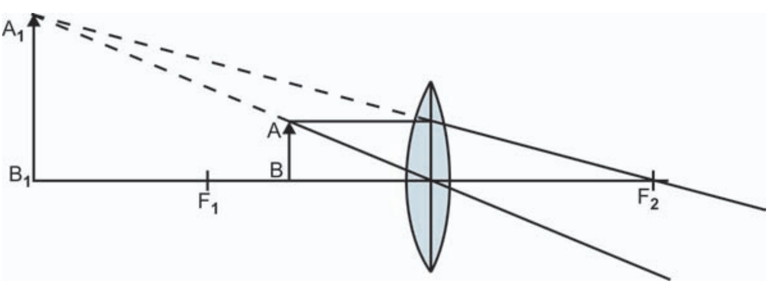


Fig. 17-2: Magnifiers optical principle. AB = Object, A_1B_1 = Image, F_1 = 1st Principal focus and F_2 = 2nd Principal focus

TELESCOPES

They are used to magnify distant objects, i.e. those lying beyond 5 metre. They may be (1) spectacle mounted—They allow the hands to remain free (2) monocular—they are easy to carry and helps where one eye is worse than the other and (3) binocular—they are rather cumbersome to carry but give binocular vision.

Optics of Telescopes

The low visual aid telescopes are basically constructed on the principle of Gallilean telescope. The Gallilean telescope consists of a convex objective lens and a concave eyepiece lens, mounted coaxially, separated by the difference between their focal length (Fig. 17-3). The optical result is an erect magnified image which is relatively undistorted by astigmatism or curvature of field. *Advantages* are (1) it is light and compact (2) it is easily mounted on a spectacle frame for either distant vision or near vision. The *disadvantages* are (1) reduced field of view due to high magnification and (2) steadiness of head is required for stable focussing of object for both distance and near vision.

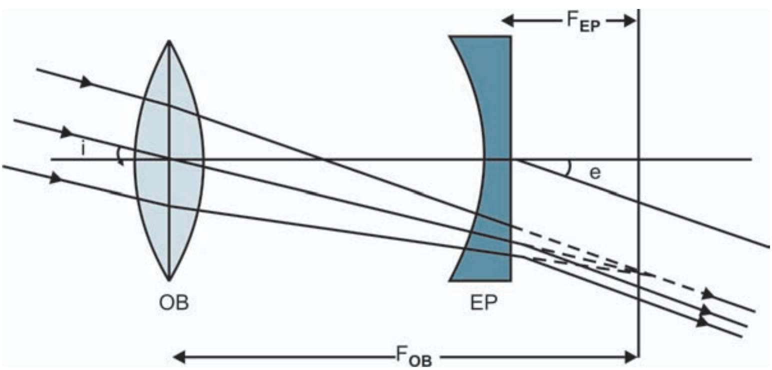


Fig.17-3: Gallilean Telescope—Optical principle. i = Angle of incidence, e = Angle of emergence, OB = Objective lens (convex), EP = Eyepiece lens (concave), F_{OB} = Focal length of objective lens and F_{EP} = Focal length of eyepiece lens

The incident rays and emergent rays are parallel. The image is magnified by increasing the angle subtended by the object at the eye, i.e. the angle i is increased to angle e. Magnification is deduced by the formula:

$$M = \frac{\text{Power of the eyepiece lens in diopters}}{\text{Power of the objective lens in diopters}}$$

PROJECTION DEVICES

These are used increasingly as low visual aids. An enlarged image of the object is projected on a screen or TV monitor for viewing at a convenient distance.

CHAPTER

18

Paediatric Eye Examination

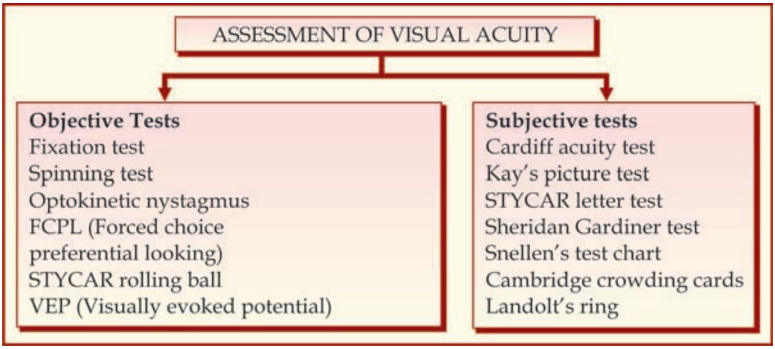
INTRODUCTION

Paediatric eye examination has always been difficult and challenging due to the lack of an objective and reproducible response. Moreover, the children are usually very apprehensive while being examined by a doctor. Often, the eye examination turns into a time consuming and frustrating effort for the eye specialist or the optometrist. To overcome this difficulty, special examination techniques are necessary for infants and toddlers. So, this chapter deals with the special techniques in history taking and examination in the management of eye diseases in paediatric age group.

Initially, create a friendly environment by keeping the children amused with toys in the waiting room. While discussing and taking history from the parents, keep the children busy with bright colourful objects. This extra effort helps in gaining the trust of the child during actual examination procedure. Due consideration should be given to parental observation of child's visual problem. Children are best examined when they are alert and not famished.

See Flow Chart 18.1.

Flow Chart 18.1: Paediatric assessment of visual acuity



OBJECTIVE TESTS

Fixation Test

- An infant's ability to fix and follow faces and bright coloured objects develops within 2–3 weeks of birth.
- A positive blink reflex to a burst of light and ability of the baby to fixate and follow faces specially that of the mother, a cartoon character in TV and coloured objects indicates presence of significant level of vision.
- Fixation should be steady and the movements should be smooth.
- This is a gross assessment of visual acuity and ocular movements.
- The ability of each eye to fixate a target centrally, steadily and to maintain the fixation (CSM) through a blink is a good indicator of visual acuity of both eyes.
- If occlusion of one eye makes the baby uneasy, it signifies that the vision is poor in the unoccluded eye.
- Observe corneal reflex with a torch, with one eye covered, alternately. Eccentric fixation is present if the corneal reflex is not central. Presence of eccentric fixation usually indicates visual acuity of 6/60 (or 20/200) or less.

Spinning Test

- In the absence of demonstrable fixation, the spinning test differentiates between blindness and low vision.

- The infant is held at arm's length and rotated to elicit vestibulo-ocular nystagmus. Slow phase of nystagmus occurs towards the direction of the rotation. Normally on stopping the rotation/ spinning, the nystagmus should stop quickly due to presence and action of fixation reflex.

Optokinetic Nystagmus (OKN)

- Nystagmus is a physiological reflex elicited by the attempt to maintain fixation on a moving set of alternate, vertical, uniform black and white stripes (optokinetic drum).
- It is demonstrable in infants just a few hours after birth.
- It is simple and may be used as a rapid screening test for assessing gross integrity of the visual system.
- Presence of optokinetic nystagmus (OKN) provides evidence of vision.

Forced Choice Preferential Looking (FCPL)

- It is based on the natural tendency of an infant to look preferentially at a patterned target than a plain one.
- It is a psychophysical test and depends on child's motor response.
- The infant is presented with Teller Test Cards containing two targets, a patterned one and a homogeneous one at a distance of 55 cm. The examiner observes the eye movement of the infant through a central peephole. Teller Test Cards set consists of 16 rectangular grey cards (26 cm × 56 cm). 15 of the cards contain a high contrast square-wave grating (12 cm × 12 cm), each of a given spatial frequency (from 0.3 to 38 cpd), either on the left or right side of the central peephole. The procedure starts with presenting the card with the lowest spatial frequency, i.e. coarser grating and proceeding to cards with finer gratings. The examiner makes an assessment, based on the infant's head and eye movements and the finest grating card the child is able to resolve. The spatial frequency of that particular card represents the visual acuity of the infant.
- FPCL is particularly useful in infants between 3 to 12 months of age, although it can be tested on children upto 3 years of age.

Stycar (Screening Test for Young Children and Retards) Rolling Ball

- Ten white spheres from 3.5 mm to 6 cm in diameter are rolled across in a well-lit room across a contrasting floor 3 metre from the child.
- Presence of pursuit eye movement implies presence of reasonable good vision.

Visual Evoked Potential (VEP)

- In normal infants, pattern–evoked visual potential testing (discussed in detail in chapter–5) demonstrated that equivalent of 6/6 (or 20/20) vision is achieved during six months and one year of life.
- However, FPCL suggests this 6/6 (or 20/20) visual acuity is achieved between one and three years of life.

SUBJECTIVE TESTS

- A variety of methods/charts/cards are available for different age groups for subjective assessment of distance visual acuity using optotypes, i.e. a symbol whose identification implies certain level of visual acuity. The suggested distant visual acuity test in different age groups are (Table 18-1):

Table 18-1: Subjective tests in different paediatric age group

1½ to 2 years of age	Cardiff Acuity Test Cards Kay's Picture Test
2 to 3 years of age	STYCAR letter test Sheridan Gardiner Test
More than 3 years of age	Snellen's test charts Cambridge crowding cards Landolt's ring

- Cardiff Acuity Test Cards and Kay's Picture Test consist of a series of cards, each with different pictures of a dog, a duck, a fish, a car, a house, etc. The viewing distance is 3 metre. The children are required to match the optotype letter/picture on a card shown by the examiner.

- STYCAR letter test is based on the letters first recognised by children (H, O, T, V and X).
- Sheridan Gardiner Test is similar in principle, adding two letters U and A, i.e. H, O, T, V, X, U and A.
- Visual acuity should be tested at distance and at near, using tests with the same optotypes. Recommended distance is 6 metres (or 20 feet). However, in children the test distance is 3 metres (or 10 feet) for distance acuity and 40 cm (or 16 inches) for near acuity.
- If amblyopia is suspected, Snellen's visual acuity chart or Cambridge Crowding Cards should be used to assess visual acuity. Because isolated optotypes will overestimate the visual acuity in amblyopic eyes.

VISUAL FIELD TESTING

- Humphrey visual field automated perimeter is used for older children.
- Confrontation method is used in younger children. One toy is used for central fixation attention, while other toy is introduced into their visual field periphery.

COLOUR VISION TESTING

- Colour vision test often helps in the diagnosis of diminished visual acuity in children.
- It also helps in monitoring progressive macular disease and optic neuropathy.
- Usually, red-green colour defects are caused by optic nerve diseases and acquired blue-yellow colour defects are caused by retinal diseases (see chapter–5 for colour vision testing in details).

OCULAR MOVEMENTS

It is easily done in infants and young children by the following tests:

Brückner's Test

An infant with squint fixates the light of a direct ophthalmoscope or torch. It is noted that the deviating eye will have a brighter red reflex than the fixating (dominant) one.

Hirshberg Test

In an infant with squint, corneal reflex will be eccentric in the deviating eye. It will be nasally displaced in exotropia, temporally in esotropia, superiorly in hypotropia and inferiorly in hypertropia. The angle of deviation is estimated by noting location of the corneal reflex in the deviating eye when light is thrown into the eyefrom 60 cm distance. Since the cornea is 12 mm in diameter, the distance from the centre of the pupil to limbus is 6 mm. Each mm of displacement of corneal reflex represents a deviation of 7°. So, the degree of deviation is calculated as follow (Fig. 18-1):

i. If the light reflex is at the pupillary border but not touching the iris–14°.
ii. If the light reflex is at the limbus–42°.
iii. If the light reflex is midway between the pupillary border and the limbus–28°.
iv. If the light reflex is midway between the pupil and the limbus–21°.

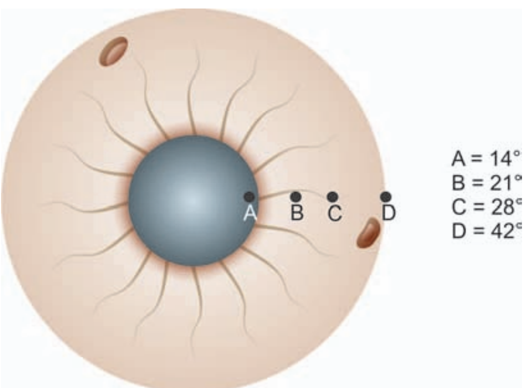


Fig. 18-1: Assessment of angle of deviation from location of corneal reflex

BINOCULAR VISION TESTING

- Presence of simultaneous macular perception, fusion and stereopsis indicates good visual acuity in each eye.
- They may be assessed using Worth 4 dot test, Titmus fly test and synoptophore.
- The Lang and Frisby tests are conducted for testing young children.

CLINICAL EXAMINATION OF THE EYE PROPER

- Examination of ocular adnexa.
- Examination of pupil–Normal pupillary reactions are present by the age of 3 (three) months.
- Refraction–Children of age group from birth to 7 years of age are at risk of developing squint and or amblyopia due to refractive error. Hence, cycloplegic refraction is very important for accurate estimation of refraction in them.

  In children cycloplegic refraction should be done after application of atropine sulphate 1% eye ointment in a schedule of twice daily for 3 consecutive days, prior to the day of retinoscopy. However, parents should be advised to discontinue the ointment if side effects, e.g. fever, flushes and irritability occur. Atropine drops should not be applied in children topically to avoid atropine poisoning by absorption from stomach through nasolacrimal passage. Atropine allergy may also develop which is treated with systemic antihistaminic and topical steroid ointment.

  Full refractive correction should be prescribed if hypermetropia is accompanied by esophoria or esotropia. Hypermetropia should be corrected with appropriate glasses to prevent amblyopia. The parents of hypermetropic child may be warned beforehand that the child may complain of blurred vision with the glasses, initially. This occurs because uncorrected hypermetropic child is used to extra accommodative effort to neutralise a portion of his hypermetropia. Usually, after a few days on continuous wearing of the glasses, the accommodation relaxes. However, if the accommodation fails to relax, cycloplegic eyedrops are advised temporarily for few days as remedial measure.

However, conventionally myopia should be corrected with weakest concave lens to achieve 6/6 (or 20/20) vision of even if accompanied by exophoria or exotropia. The idea is to stimulate accommodation, convergence and prevent squint.

Amblyopia is more common in hypermetropia than in myopia. However, unilateral myopes are also at significant risk to develop amblyopia. In case of anisometropia of more than 4.00D, contact lenses should be advised in place of spectacles to maintain binocular vision. In children with refractive errors, refraction should be repeated every year.

- Ophthalmoscopy—It is performed using both indirect ophthalmoscope and direct ophthalmoscope.
- Intraocular pressure measurement—Conventionally, IOP measurement in children is done with the Perkins handheld tonometer under topical anaesthesia (0.5% proparacaine HCl) or general anaesthesia. Some examiners prefer Tonopen/Non-contact tonometers over Perkins tonometer (discussed in detail in chapter–16). Goldmann applanation tonometry is usually possible after the age of 6 years.
- Examination under anaesthesia (EUA)—Examination under anaesthesia is often needed for IOP measurement, in uncooperative children, removal of foreign body, ophthalmoscopy, gonioscopy, etc.

MILESTONES—NORMAL VISUAL MATURATION AND REFLEXES

Development of normal visual function is extremely critical in the first 6-8 weeks after birth. This critical period extends upto seven (7) years of age (Table 18-2). Any deprivation of stimulation during this period in the form of cataract or refractive error may lead to nystagmus and amblyopia. The visual development remains unstable during this period and any stimulation deprivation acquired during this critical period may interrupt visual maturation process. Normal visual development is shown in tabular form (Table 18-2).

Table 18-2: Milestones–Normal visual maturation

Visual function	*Period after birth*
Optokinetic nystagmus (OKN)	Few hours after birth
Fix and follow faces and bright coloured objects	2–3 weeks
Tear secretion starts	3 weeks
Pupillary reaction	3 months
Positive blink reflex	2–5 months
Psychic tear reflex (weeping)	4 months
Foveal maturation	4 months
Reach for objects	6 months
Binocular vision and stereopsis	6 months
Contrast sensitivity	7 months
Permanent iris colour	9–12 months
Adult level of visual field	12–15 months
Completion of optic nerve myelination	7–24 months
Visual acuity of 6/6 (or 20/20)	24–30 months

NORMAL VISUAL ACUITY MATURATION (AGE-RELATED)

Normal age-related visual acuity estimate varies depending upon the test method employed. By the age of 30 months (Table 18-3) it should reach 6/6 (or 20/20). However, pattern visual evoked potential (PVEP) estimates 6/6 vision is achieved between 6-12 months after birth.

Table 18-3: Progression of normal visual acuity

Age	*Visual acuity (Snellen's)*
At birth	1/60 to 3/60
At 4 months	6/60
At 6 months	6/36
At 1 year	6/18
At 2–2½ yrs	6/6

If a child is amblyopic and is under 7 years of age, the amblyopia can be cured by patching, i.e. occlusion of the eye with better vision. It is observed that at 1 year of age, patching may be successful to cure amblyopia within 1 week. However, it may take a year to achieve the same result if it is started at 6 years of age. Occasionally, after the age of 7 years pleoptics can help restore normal visual acuity in combination with occlusion upto the age of maximum 14 years.

Stimulus deprivation in both eyes results in development of a pendular nystagmus on attempted fixation by the age of 6 months. Hence, it is very important and critical to examine a child with visual complaints and treat as early as possible.

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