# APPLIED ANATOMY OF THE EYE

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GRUNE & STRATTON NEW YORK and LONDON

Library of Congress Catalog Card No. 60-5426


GRUNE & STRATTON, INC.
381 Park Avenue South
New York 16, N. Y.

Acknowledgment is made of the courtesy of Sir Stewart Duke-Elder and Mr. Henry Kimpton, London, England, to permit use of illustrative material from *Duke-Elder, "Textbook of Ophthalmology," Vol. I, 1941;* and of Verlag Franz Deuticke, Vienna, to permit use of illustrations from *Salzmann, "Anat. u. Hist. des menschlichen Augapfels,"* 1912. Exact citations are given at the appropriate points in the text.

Printed in U.S.A. (K-A)

The Family of Dr. Alfred Kestenbaum wishes to express its deep appreciation to Dr. Arthur Linksz, a long time friend and colleague of the Author, who gave of his valuable time in assisting the publishers in the final editing of this work.

At the time of Dr. Kestenbaum's passing, the manuscript had been completed. Dr. Linksz reviewed it, answered queries by the publishers on technical matters, helped arrange a cross-referencing system, and reviewed the illustrations.

Dr. Linksz's help in the publication of this book has been invaluable.

# Introduction

THIS BOOK represents the contents of lectures on the "Anatomy of the Eye, including its Nervous Connections" at the New York University Post-graduate School. The lectures did not only deal with anatomy proper but also with its relations to physiology and surgery: "applied anatomy." This book intends not only to serve the learning and understanding of anatomy but also to help the surgeon in anatomic questions.

The book is based on the presentation of anatomy in Duke-Elder's standard *Textbook of Ophthalmology* and Wolff's excellent textbook of anatomy; the study of these two books is indispensable for the student. Furthermore, for this book Salzmann's classic book of *Anatomy of the Eye*, Gray's *General Anatomy*, Ranson's *Anatomy of the Nervous System*, Rea's *Neuro-ophthalmology*, and the author's book on *Neuro-ophthalmological Examination*, were consulted. The material was modified from four points of view:

1) The relations between anatomic data and surgical and clinical requirements were emphasized.

2) The correspondences between anatomic facts and physiological and biological requirements were considered. In this way, anatomy should become a subject of understanding instead of memorization.

3) Presentations were schematized in order to facilitate the memorizing.

4) New studies were added.

As matters serving the first purpose may be mentioned: chapters about the different dimensions found in optical measurements of the living eye if compared with anatomic measurements; the different size of an angle degree if it is measured along the sclera or along the cornea, or with the perimeter and the consequence of these differences for the clinics; the calculation of the "limbus distance" of a focus in the fundus from its "perimeter angle" ("limbus-number"); the eccentrical tubular field after occlusion of the central artery; further conceptions of a "surgical equator" of the eye and of an anatomic and physiologic vertical midline of the retina; a registration method of the retinal vessels; stress of the importance of the course of the optic pathway for the pathology, etc.

The second aim has been served by studies of the connection between "Hering-Hillebrand's deviation" and the temporal bulge of the eyeball; of the change of the luster of the cornea due to a change in the sympathetic tonus; of the role of the wing cells in the persistent coming and going of

# Contents

CHAPTER 1

# General Anatomy of the Eyeball

## COATS OF THE EYEBALL

**1.1** THERE ARE FOUR COATS which form the eyeball* (fig. 1):

a) *The fibrous tunic* consists of the sclera or "white tunic" posteriorly and the cornea anteriorly. The sclera occupies about five-sixths and the transparent cornea about one-sixth of the horizontal circumference of the eyeball. The border between the cornea and the sclera is called the limbus.

b) *The vascular tunic or uvea* consists of the choroid, the ciliary body, and the iris.

c) *The pigment epithelium of the retina, or in short, pigment epithelium.* This coat extends as a special membrane from the optic disk to the ora serrata, i.e., the anterior margin of the retina. Some authors, however, describe this coat as a part of the retina, so that they count only three coats of the eyeball.

d) *The retina, or retina proper or nervous tunic,* reaches as a special tissue from the optic nerve to the ora serrata. The site of entrance of the optic nerve into the eye is called the optic disk or nervehead. Ophthalmoscopically, it is referred to as the optic disk or the papilla. Anatomically, the nervehead or disk consists of a perforated membrane called the lamina cribrosa and of the perforating nervous fibers. The lamina cribrosa is a continuation of the sclera and the choroid, and the perforating nervous fibers are a continuation of the retina.

In addition to the four coats proper, the eyeball is enveloped by:

*Tenon's capsule,* which envelops the eyeball from the optic nerve forward almost to the limbus. At the sites of insertion of the external eye

*Usually, only three coats are enumerated, i.e., fibrous tunic, vascular tunic and retina. The pigment epithelium is frequently described as a part of the retina. Clinically, in a so-called retinal detachment, only the retina proper is detached and the pigment epithelium retains its contact with the choroid. However, the pigment epithelium has an ectodermal origin just as the retina proper. Therefore, it seems preferable to describe the pigment epithelium as a separate coat.

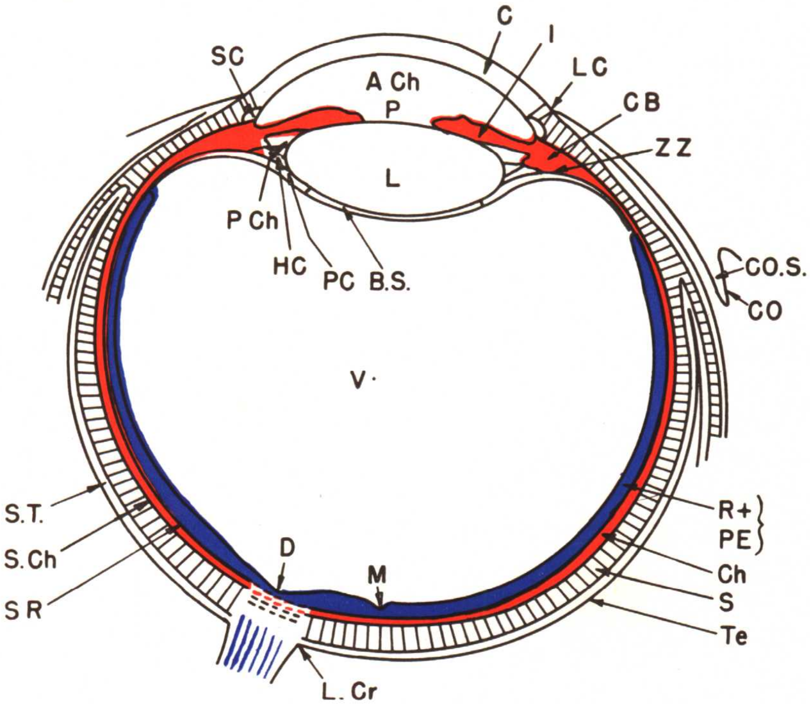


Fig. 1.—Organs and Spaces of the Eyeball

| | | | | | |
|---|---|---|---|---|---|
| A CH | = | anterior chamber | P Ch | = | posterior chamber |
| B. S. | = | Berger's space | P C | = | Petit's canal |
| C | = | cornea | P E | = | pigment epithelium |
| C B | = | ciliary body | P | = | pupil |
| Ch | = | chorioid | R | = | retina proper |
| C O | = | conjunctiva | S | = | sclera |
| Co.S. | = | conjunctival sac | S C | = | Schlemm's canal |
| D | = | disc or papilla | S. Ch | = | suprachorioidal space |
| H C | = | Hannover's canal | S R | = | subretinal space |
| I | = | iris | S. T. | = | subtenonian space |
| L | = | lens | Te | = | Tenon's capsule |
| L C | = | limbus of the cornea | V | = | vitreous body |
| L. Cr | = | lamina cribrosa | Z Z | = | zonula of Zinn (suspensory ligament of the lens) |
| M | = | macula lutea | | | |

muscles, Tenon's capsule is carried backward over and around each of the tendons as a kind of sheath.

*The conjunctiva,* as a special membrane, starts at the limbus and covers the anterior part of the eyeball.

## SPACES BETWEEN AND WITHIN THE TUNICS

**1.2** 1. Between the sclera, externally, and the choroid and ciliary body, internally, lies the suprachoroidal space. Anteriorly, it is an empty space, while posteriorly it is occupied by the suprachoroidal trabeculae. Pathologically this space may be extended by fluid and thus forms a real space. Such a condition is called detachment of the choroid.

2. There is no space between the choroid and the pigment epithelium. The innermost part of the choroid and the outermost part of the pigment epithelium together form a membrane called Bruch's membrane or lamina basalis.

3. Between the pigment epithelium and the retina proper there is a free but virtual space called the subretinal space. Dilatation of this virtual space by fluid to a real space is called retinal detachment or retinal separation.

4. In addition, the subtenonian or episcleral space lies between Tenon's capsule and the sclera. It is not a free space but is more or less occupied by fine trabeculae called episcleral tissue.

5. Below the conjuctiva, i.e., between the conjunctiva and the sclera (just behind the limbus) and Tenon's capsule (more posteriorly), there is no free space, but only loose tissue called subconjunctival tissue.

## ORGANS AND SPACES WITHIN THE WALLS OF THE EYEBALL

**1.3** 1. The anterior chamber lies between the cornea and a small part of the sclera anteriorly, and posteriorly to a small part of the ciliary body, the iris and the lens. The anterior chamber is filled with aqueous humor. Its periphery is called the "angle of the anterior chamber," or, in short, "the angle."

2. Antero-lateral to the "angle," and separated from it by the "meshwork of the angle," there is a kind of circular space called Schlemm's canal. Normally, this canal is filled with aqueous humor.

3. The posterior chamber lies between the posterior surface of the iris, the lens, and the anterior surface of the vitreous body. It is filled with aqueous humor.

4. The lens consists of the lens proper and the surrounding capsule.

5. The suspensory ligament of the lens or Zonulae of Zinn attaches the lens to the ciliary body. It is now usually regarded as a modified part of the vitreous body.

6. The more or less virtual space between the anterior and the more

posterior bundles of the suspensory ligament, around the equator of the lens, is called Hannover's canal.

7. The more or less virtual space between the posterior layer of the suspensory ligament and the vitreous body proper is described as Petit's canal.

8. The vitreous body proper occupies the large posterior portion of the eyeball. The vitreous body is fixed to the lens by a ring-shaped band (about 1 mm. behind the equator) called hyaloideocapsular ligament (Wieger). On its posterior side, the isolated lens has a corresponding ring-shaped line called Egger's line. The potential space between the anterior surface of the vitreous body and the posterior surface of the lens within Egger's line is called Berger's space.

## DIFFERENCES BETWEEN THE ANATOMIC AND OPTIC DIMENSIONS OF THE EYE

**1.4** The anatomic dimensions of the eye, as given below, represent average anatomic measurements.* These measurements differ essentially from those found in the living eye by optic methods, e.g., ophthalmoscopy, corneal microscopy and refraction (Helmholtz, Tscherning, Gullstrand, etc.).

The differences between the dimensions in the *dead* eye (anatomic measurements) and the *living* eye (optic methods) are demonstrated in figure 1a. The upper half of the diagram includes the optic dimensions and the lower half shows the anatomic measurements.

The great differences between the two sets of data have been attributed partially to changes of the tissue in the dying or dead eye. In addition, however, two groups of factors are responsible for differences in dimensions between the living and the dead eye.

In the living eye the outer coats (sclera and cornea) are stretched to a certain degree because of the intra-ocular tension. This stretching results in:

a) A greater volume of the eyeball and, therefore, an increase in the length of all its diameters. Actually, the average anatomic diameter was recorded as 24.15 mm. In optic measurements of the living eye, the distance between the corneal surface and the second focal point was found to be at least 24.4 mm. (see below). Since this second focal point normally coincides with the external layers of the retina proper, and the thickness of the pigment epithelium, choroid, and sclera may be accepted as 1.2 mm., the sagittal diam-

*See Duke-Elder, p. 33 ff.

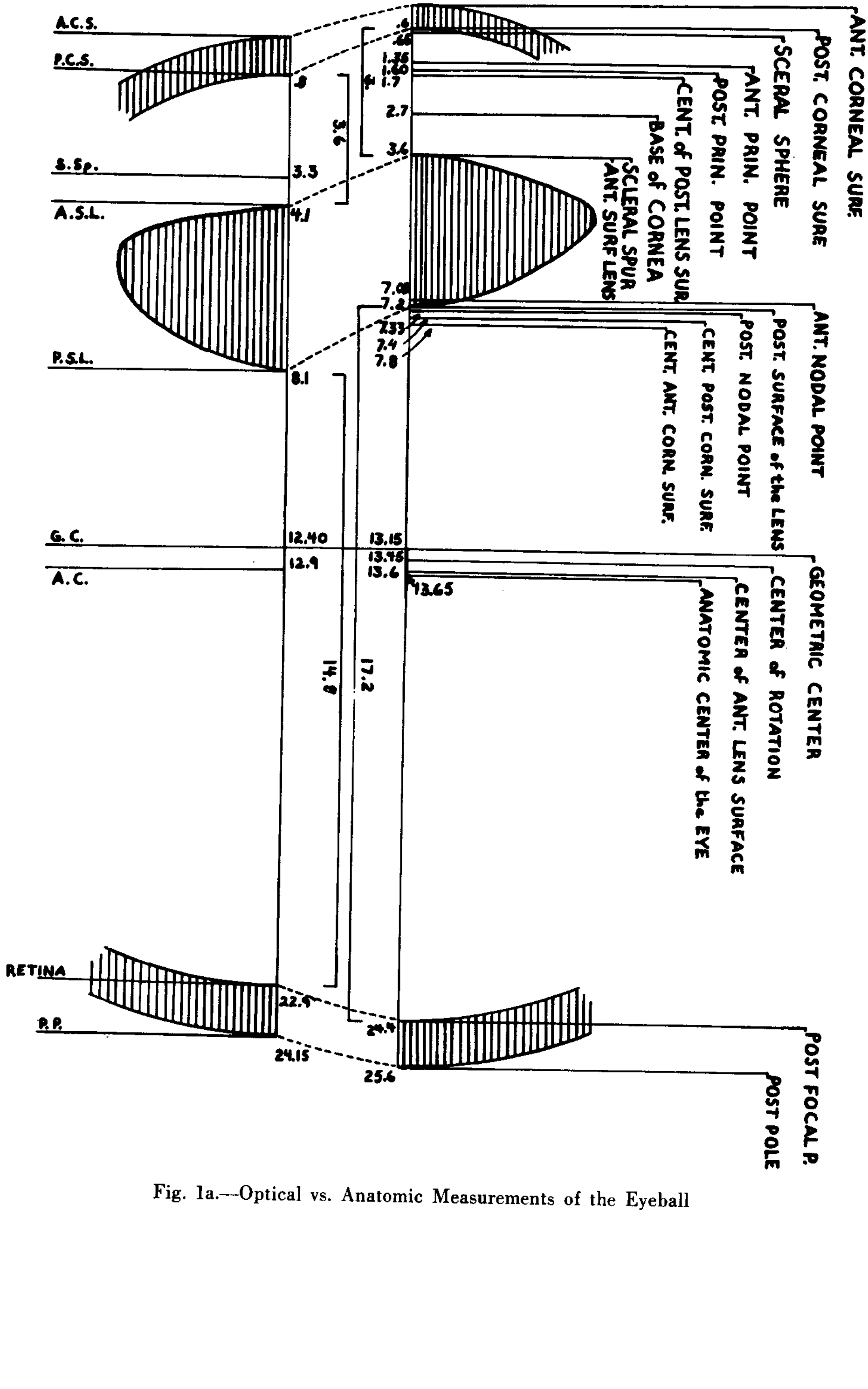


Fig. 1a.—Optical vs. Anatomic Measurements of the Eyeball

eter of the living eye is at least 25.6 mm. Therefore, the optic diameter is 1.2 mm. or about 5 per cent longer than the anatomic one.

b) A thinning of the outer coats (sclera and cornea) due to the lengthening of the diameters. Actually, the thickness of the cornea in its center was found to be 0.8 mm. anatomically, but approximately 0.6 mm. optically. Other factors, such as swelling after death, must be taken into consideration (§2.17). Since the corneal tip is slightly prominent above the scleral sphere, the radius of the sclera is approximately 25/2 = 12.5 mm.

In the living eye there is a difference in the osmotic pressure between the vitreous humor behind the lens and the aqueous humor in front of the lens because the former contains much more protein than the latter.

This difference in osmotic pressure results in a "forward-shift" of the lens in the living eye. The lens is pushed forward to such a degree that the resulting stress in the tissues, at which the lens is fixed, balances the increased pressure from behind.

Actually, the depth of the anterior chamber was found to be (in emmetropia) 3 to 3.6 mm., or an average of 3.3 mm. (anatomically); and 3.54 — 1.15 = 2.39 mm. (optically, according to Tscherning); and 3.6 — 0.5 = 3.1 mm. (optically, according to Gullstrand).

The average depth of the vitreous body may be calculated as follows:

a) Anatomically

| | |
|---|---|
| Thickness of the cornea | 0.8 mm. |
| Anterior chamber | 5.3 mm. |
| Thickness of the lens | 4.0 mm. |
| Sclera, choroid and retina, about | 1.6 mm. |
| | 11.7 mm. |

This figure subtracted from the Sagittal diameter of the eyeball (24.15 mm., Duke-Elder) yields an average depth of the vitreous body of 12.45 mm.

b) Optically

| | *Tscherning* | *Gullstrand* |
|---|---|---|
| From corneal surface to second focal point | 24.75 mm. | 24.39 mm. |
| From corneal surface to posterior surface of the lens | 7.6 mm. | 7.2 mm. |
| | 17.15 mm. | 17.19 mm. |

Although the anterior chamber in the living eye is shallower than in anatomic measurements, the vitreous body was found to be much larger in optic measurements of the living eye than in anatomic measurements (differences of about 2.3 mm. or 15 per cent). These proportions are compatible with the postulated "forward-shift" of the lens in the living eye.

An increase of this physiologic "forward-shift" of the lens (a further increase of the vitreous space and decrease of the anterior chamber) is found pathologically, e.g., in so-called narrow-angled glaucoma or after paracentesis and outflow of the aqueous humor. A decrease of the forward-shift (deeper anterior chamber) is seen following an injury with perforation in the posterior part of the sclera.

## DIMENSIONS OF THE EYEBALL

**1.5** Anatomically, the sagittal diameter of the eyeball measures approximately 24 (24.15) mm.; its transverse diameter, 24 mm.; and its vertical diameter 23.5 mm. Thus, the eyeball deviates only slightly from a sphere.

The radius of the scleral part of the eyeball is about 12 mm. (optically, 12.5 mm.)

If the horizontal cross section of the sclera formed a complete circle, the "scleral circle," its circumference would be 24.15 times $\pi = 75.8$ mm.; actual anatomic measurements gave an average of 75 mm. Based on the optically determined diameter, the circumference would be $2 \times 12.5 \times \pi = 78.5$ mm. Due to the prominence of the cornea and the presence of the temporal bulge (§ 1.7), the actual circumference of the living eye may be estimated as approximately 81 mm.

If 75 mm. corresponds to 360 degrees, 1 mm. equals $\frac{360}{75} = 4.8°$.

If the size of the living eyeball and the asymmetry of the eyeball, as described later (§ 1.6) is considered, and if the optically determined numbers, i.e., the measurement of the living eye, are taken into consideration, an average ratio of 1 mm. = 4.6° for the nasal side, and a ratio of 1 mm. = 4.4° for the temporal side are obtained. For clinical purposes the approximate ratio of 1 mm. = 4.5° may be used. This ratio is valid for all measurements performed at the scleral surface.

IN THE MEASUREMENT OF STRABISMUS. If the deviation of the strabismic eye from the straight position is measured along the sclera, 1 mm. equals 4.5 degrees or 8 prism diopters.

One prism diopter indicates a 10 mm. deviation of the visual axis at 1,000 mm. The limbus is approximately 12.5 mm. distant from the rotation center of the eye. Therefore, 1 mm. deviation of the limbus corresponds to $\frac{1{,}000}{12.5 \times 10}$ = 8 prism diopters.

IN EYE MUSCLE PARESIS. The extent of possible excursion in the concerned direction of the eye is measured numerically by determining the position of the limbus in the primary position and its position after maximum excursion by means of a ruler; the extent is compared to that of a normal eye in the same direction. One millimeter of motility corresponds to 4.5 degrees.

IN SURGERY OF STRABISMUS. The extent of the surgical lengthening (recession) or shortening (resection) of the muscle tendons are measured in millimeters. One millimeter resection of one muscle combined with one millimeter recession of the antagonist muscle results in one millimeter rotation of the eyeball. One millimeter rotation corresponds to approximately 4.5 degrees or 8 prism diopters.

IN SURGERY OF NYSTAGMUS. The required rotation is achieved by equal resection of one muscle and resection of its antagonist.

IN SURGERY OF RETINAL DETACHMENT. Because the surgery in this disease consists of closure of the existing tear in the retina by cauterization, this tear must be located exactly. The localization may be done in the following way: The tear is located with the ophthalmoscope. The direction is determined by means of a perimeter in perimetric degrees. The number of perimeter degrees is converted into degrees at the surface of the sclera, where the operation must be performed. The calculated degrees on the surface of the sclera are further computed in order to obtain the distance of the site from the limbus and is expressed in millimeters. For this last computation the ratio of 1 mm. = 4.5° is used again. The computation can be simplified by use of the limbus number (see table page 124 and § 4.31).

The sclera occupies about five-sixths or 300 degrees (more exactly, 304 degrees) of the circumference of the sphere of the eyeball and the cornea occupies about one-sixth or 60 degrees (more exactly, 56 degrees).

Because the cornea occupies about one-sixth of the circumference of the eyeball, the diameter of the base of the cornea and the two radii of the eyeball at the extremities of the diameter form an almost equilateral triangle. Therefore, the "diameter" of the cornea practically equals the radius of the eye and measures about 12 mm. (the average is 11.6 mm., according to Duke-Elder). The knowledge of this equilateral triangle is helpful in drawing the eyeball.

The cornea itself has a radius of curvature of about 8 mm. (average finding, 7.8 mm.).*

Scleral sphere and corneal sphere (fig. 2). The sphere with approximately

*The term "diameter of the cornea" is usually applied to the diameter of the base of the cornea, i.e., the distance from limbus to limbus; the term "radius of the cornea" usually refers to the radius of curvature of the cornea.

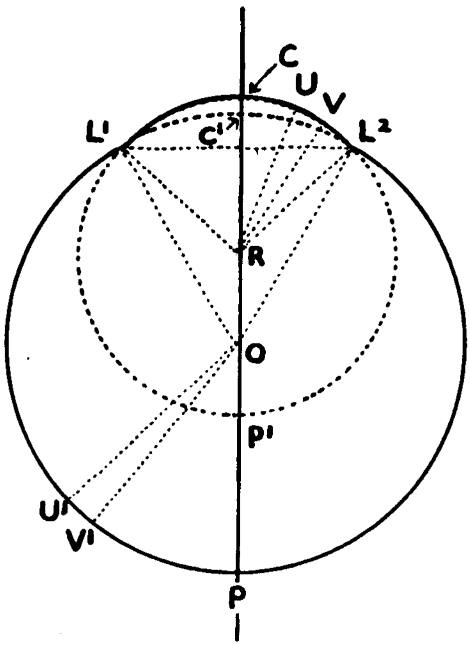


Fig. 2.—Scleral and Corneal Spheres

$L^1$ $L^2$ = limbus
$L^1$ P $L^2$ $C^1$ = scleral circle
$L^1$ C $L^2$ $P^1$ = corneal circle
O = center of the scleral circle
R = center of the corneal circle
$U^1$–$V^1$ = 1 mm. on the scleral surface
U–V = 1 mm. on the corneal surface

12.5 mm. radius (O P or $L^1$O), of which the sclera forms a part, may be termed the "scleral circle." Sixty degrees of this sphere (circle) are occupied by the cornea (arc $L^1C^1L^2$), arc $L^1PL^2$ is 300° of the scleral circle. The sphere, of which the cornea forms a part and which has a radius of approximately 8 mm., may be called the "corneal sphere," and its cross section the "corneal circle."

The distance between 0, the center of the scleral circle, and R, the center of the corneal circle, is more than 5 mm. (13.1 — 7.8).

The arc of the scleral sphere that is occupied by the cornea measures approximately 11.5 mm.

The arc of $L^1CL^2$ in the corneal circle may be calculated from the diagram in figure 2. If the corneal diameter, d = 11.6 mm., and the radius of curvature of the cornea $L^1R$ = 7.8 mm.: