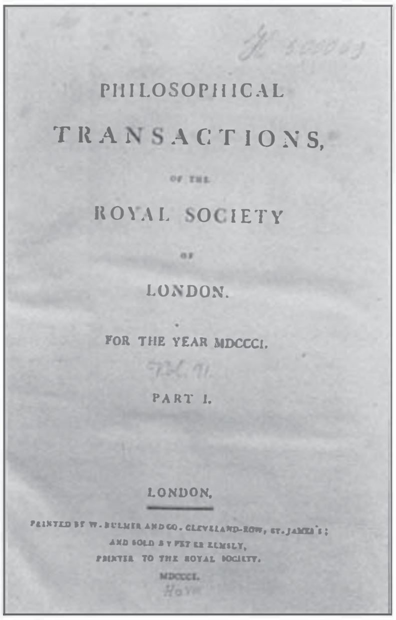
Chapter VII

Corneal Immersion by Thomas Young

INTRODUCTION

Whilst France was confronted by the violence of the years of Revolution, Natural Science experienced phenomenal expansion in the British Isles. *The Royal Society of London* became the focus of great activity and was a pedestal for the best researchers of this era. It was to this *Royal Society* that *Thomas Young*, then still a medical student and hardly turned 20, submitted his first communication on the 30th May 1793, entitled ***"Observations on Vision"*** (1).



PHILOSOPHICAL
TRANSACTIONS,
OF THE
ROYAL SOCIETY
OF
LONDON.
FOR THE YEAR MDCCCI.
PART I.
LONDON,
PRINTED BY W. BULMER AND CO. CLEVELAND-ROW, ST. JAMES'S;
AND SOLD BY PETER ELMSLY,
PRINTER TO THE ROYAL SOCIETY.
MDCCCI.

Figure 7 - 1

Title page of the "Philosophical Transactions of the Royal Society of London", 1801.
(Library of the Faculty of Sciences of the University Louis Pasteur, Strasbourg)

After his admission to the *Royal Society*, he gave another lecture there on the 27th November 1800, with the title of ***"On the Mechanism of the Eye"***, that was published in the following year in the *"Philosophical Transactions of the Royal Society"*. In this memoir, *Young* describes with illustrations several experiments including one on neutralization of corneal dioptric power in which he immersed his own eye in the water contained in a tubular structure, which was shut at one extremity by a lens consisting essentially of the eyepiece (ocular) of a botanical microscope (2). *(Figure 7-1)*

This initiative earns *Young* the distinction of being cited among the pioneers of the neutralization of corneal dioptric power and of contact systems. This study concentrates on the following aspects:

- the reproduction and analysis of the passage concerned, which is paragraph VIII of the lecture read on 27th November 1800 to the *Royal Society of London*,
- placing *Young's* lecture and certain significant passages in context for his ophthalmic work and the history of ophthalmology,
- comparison of these aspects with the specifics of the neutralization of corneal dioptric power and the properties of contact lenses,
- finally, referencing the citations of *Young* by certain historians.

1. Richard Brocks read Young's paper of 1793 to the Royal Society of London. In this paper, Young attributed accommodation to changes in the curvature of the crystalline lens. In 1800, he rectified the error in this communication of an imagined "muscular activity" of the fibers of the crystalline lens that he described.

2. Young 1801, p. 57-58. In my analyses, I am following the original text that he presented on 27th November 1800 (published in 1801 in the Philosophical Transactions of the Royal Society of London). Certain authors refer to subsequent editions. Young's text was republished in 1807 with some changes made by its author in "A Course of Lectures on Natural Philosophy and Mechanical Arts", and again in 1855 in a posthumous collection.
The first volumes of the Philosophical Transactions of the Royal Society of London did not include any numbering of the volumes (see Figure 7-1). The Philosophical Transactions for the year 1801, consulted at the Library of the Faculty of Sciences of the Louis Pasteur University in Strasbourg, corresponds to volume 91; Herschel (1829, p. 398) also refers to "Vol. XCI". One encounters other references: "Vol. 92" in Mann (1938), "Vol. XVII" in Hirschberg (1899-1918, § 460 p. 453, note 2), "Vol. XXII" in Tscherning (1894), "Vol. LXXX" in Donders, (according to Hirschberg}, "Vol. 16" in Rosenthal, (1996).

1 - SOURCE DOCUMENTS

1.1 - "*ON THE MECHANISM OF THE EYE*" (1800)

(Figures 7- 1)

Young's lecture to the *Royal Society of London*, on the 27th November 1800, that was entitled ***"On the Mechanism of the Eye"*** was recorded in the *Philosophical Transactions of the Royal Society of London*.

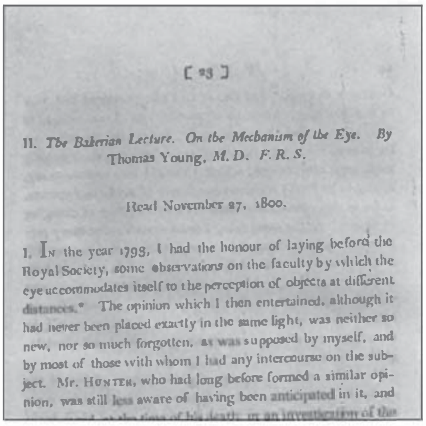
The text is 66 pages long, to which are added 4 pages of legends and six plates (57 illustrations).

The paper constitutes a basic work on ocular physiology including inter alias a description of the ocular constants and parameters, as well as corneal astigmatism and additionally definite proof that accommodation is due to changes in the crystalline lens.

The Experiment of Neutralization of Corneal Dioptric Power in Paragraph VIII

(Figure 7 – 2)

In paragraph VIII at page 57 and 58 of his lecture, *Thomas Young* describes the experiment in which he neutralizes his own corneal dioptric power while accommodating at near. His wish is evidently to prove that accommodation is not due to the cornea, because it occurs in an identical manner when the corneal dioptric power is neutralized.


[23]

II. *The Bakerian Lecture. On the Mechanism of the Eye.* By Thomas Young, *M. D. F. R. S.*

Read November 27, 1800.

1. IN the year 1793, I had the honour of laying before the Royal Society, some observations on the faculty by which the eye accommodates itself to the perception of objects at different distances.* The opinion which I then entertained, although it had never been placed exactly in the same light, was neither so new, nor so much forgotten, as was supposed by myself, and by most of those with whom I had any intercourse on the subject. Mr. HUNTER, who had long before formed a similar opinion, was still less aware of having been anticipated in it, and

Figure 7 - 2

Thomas Young: "On the mechanism of the eye. - read November 27, 1800".
Page 23 of the "Philosophical Transactions of the Royal Society of London for the Year 1801".
(Library of the Faculty of Sciences of the University Louis Pasteur, Strasbourg)

Young's description is modeled on a mathematical demonstration:

- description of experimental material, i.e. an eyepiece, consisting of a tube with a lens at one end and open at the other taken from a botanical microscope and filled with water. The eye is submerged in this bath and looks through the optical system thus constructed,
- experimental results, with and without accommodation,
- critical discussion of the method.

1.1.1. - THE EXPERIMENTAL SET-UP

(Figure 7 – 3)

The first few sentences of paragraph VIII of *Young's* lecture describe the experimental set-up: *Young* removes the eyepiece of a small botanical microscope consisting of a hollow metal cylinder, a '*socket*' 5 mm in length (but of which the diameter is not known), and which is shut at one of its extremities by a biconvex lens of 20 mm radius of curvature, i.e. equivalent to 5 diopter of plus power. He coats the border of the cylindrical container with

> would be very readily perceptible by some of the experiments related ; and the whole alteration of the eye requires one-fifth.
>
> But a much more accurate and decisive experiment remains. I take out of a small botanical microscope, a double convex lens, of eight-tenths radius and focal distance, fixed in a socket one-fifth of an inch in depth ; securing its edges with wax, I drop into it a little water, nearly cold, till it is three-fourths full, and then apply it to my eye, so that the cornea enters half way into the socket, and is every where in contact with the water. (Plate III. Fig. 13.) My eye immediately becomes presbyopic, and the refractive
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Figure 7-3

Thomas Young: "On the mechanism of the eye".
Passage on the lower part of page 57 of the "Philosophical Transactions of the Royal Society of London for the Year 1801" describing the experimental set-up.

wax and then fills it three quarters full with water. *Young* then places his own eye in the filled container, thus bringing his cornea in contact with water:

"But a much more accurate and decisive experiment remains. I take out of a small botanical microscope, a double convex lens, of eight-tenths radius and focal distance, fixed in a socket one-fifth of an inch in depth; ***securing*** *its edges with wax, I drop into it a little water, nearly cold, fill it three-fourths full, and then apply it to my eye, so that the cornea enters* ***half way*** *into the socket, and is everywhere in contact with water (Plate III, Fig. 13)."* (3)

1.1.2 – Plate III, figure 13 and his legend
(Figures 7 – 4 & 7 – 5)

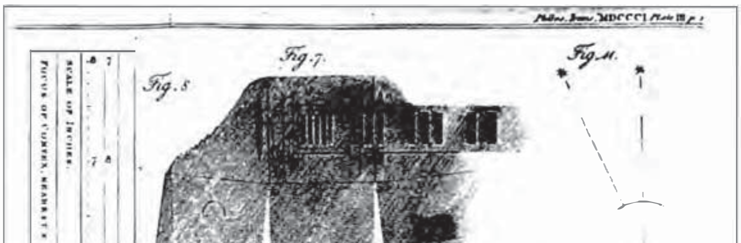


Figure 7-4

Thomas Young: "On the mechanism of the eye" - Plate III.

3. Young 1801, p.57. The metric equivalents of the dimensions indicated are: 20 mm for the radius of curvature and the focal distance of the lens, 5 mm for the depth of the water-filled cylindrical metal microscope eyepiece tube, called by Young 'socket'. I shall return later to the differing interpretations of this passage with particular reference to specific passages e.g. "securing its edges with wax" and "enters halfway into the socket".

86 *Dr.* YOUNG'S *Lecture*

Fig. 12. Diagonal scale drawn on a looking-glass.
Fig. 13. The method of applying a lens with water to the cornea.
Fig. 14. The appearance of a spectrum occasioned by pressure; and the inflection of straight lines seen within the limits of the spectrum.
Fig. 15. An illustration of the enlargement of the image, which would be the consequence of an elongation of the eye: the images of the candles which, in one instance, fall on the insertion of the nerve, falling, in the other instance, beyond it.

Figure 7-5

Thomas Young: "On the mechanism of the eye" - Legend on plate III.
Upper part of page 86 of "Philosophical Transactions of the Royal Society of London for the Year 1801"

The text refers especially to figure 13 of plate III. The legend to this figure at the page 86 indicates: *"Fig. 13. The method of applying a lens with water to the cornea". (4)*

1.1.3 - Neutralization of the Dioptric Power of the Cornea and posterior Surface of the Microscope Eyepiece *(Figure 7 – 6)*

The water contained in the cylinder of the microscope eyepiece neutralizes the refractive power of the two surfaces in contact with it, i.e. the dioptric power of the anterior corneal surface and the also of the posterior surface of the convex lens from the microscopic eyepiece. The remaining refractive power is solely that of the anterior surface of the lens of the eyepiece that is insufficient to provide clear vision. *Young* describes that, from the fact of neutralization by water of the refractive power of the corneal surface and the substitution of this surface by the new structure with its own dioptric power consisting of the external surface of the lens, his eye becomes 'presbyopic'. In order to make the eye emmetropic, it is necessary to correct it by a convex lens of 5 diopter:

58 *Dr.* YOUNG'S *Lecture*

power of the lens, which is reduced by the water to a focal length of about 16 tenths, (Cor. 5. Prop. IV.) is not sufficient to supply the place of the cornea, rendered inefficacious by the intervention of the water; but the addition of another lens, of five inches and a half focus, restores my eye to its natural state, and somewhat more. I then apply the optometer, and I find the same inequality in the horizontal and vertical refractions as without the water; and I have, in both directions, a power of accommodation equivalent to a focal length of four inches, as before. At first sight indeed, the accommodation appears to be somewhat less, and only able to bring the eye from the state fitted for parallel rays to a focus at five inches distance; and this made me once imagine, that the cornea might have some slight effect in the natural state; but, considering that the artificial cornea was about a tenth of an inch before the place of the natural cornea, I calculated the effect of this difference, and found it exactly sufficient to account for the diminution of the range of vision. I cannot ascertain the distance of the glass lens from the cornea to the hundredth of an inch; but the error cannot be much greater, and it may be on either side.

After this, it is almost necessary to apologize for having stated the former experiments; but, in so delicate a subject, we cannot have too great a variety of concurring evidence.

IX. Having satisfied myself that the cornea is not concerned

Figure 7-6

Thomas Young: "On the mechanism of the eye".
Passage on the upper part of page 58 of "Philosophical Transactions of the Royal Society of London for the Year 1801" describing the neutralization of the dioptric power of the cornea and posterior surface of the microscope eyepiece.

"My eye immediately becomes presbyopic, and the refractive power of the lens, which is reduced by the water to a focal length of about 16 tenths, (Cor. 5. Prop IV) is not sufficient to supply the place of the cornea, rendered inefficacious by the intervention of the water; but the addition of another lens, of five inches and a half focus, restores my eye to its natural state, and somewhat more" (5)

Young specifies that, taking account of the presence of the biconvex lens fixed in the socket of the microscopic eyepiece, but of which one surface is neutralized by water, the correction to establish emmetropia must be 7.5 diopter.

4. Young 1801, p. 86.
5. Young 1801, p. 57-58.

1.1.4 - Measurements with and without Accommodation

After making his eye emmetropic and optically neutralizing his cornea, *Young* moves forwards to various measurements including that of the amplitude of accommodation with an optometer of his own invention (6). In the course of making this measurement, he determines that, in the eye of which the corneal dioptric power has been neutralized, neither the lenticular astigmatism with which that eye is affected has disappeared nor the power of accommodation been modified (7).

"I then apply the optometer, and I find the same inequality in the horizontal and vertical refractions as without the water; and I have, in both directions, a power of accommodation equivalent to a focal length of four inches, as before." (8)
Young concludes from these observations that accommodation is not a corneal phenomenon.

1.1.5 - Critique of the Methodology

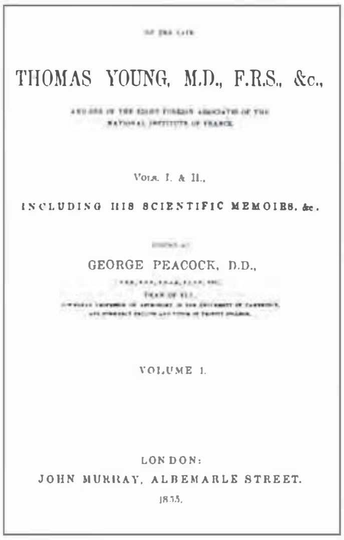
Finally, *Young* submits his observations to critical review. He accepts, as fact, that the measurements are not perfectly precise, because he was unable to determine accurately the distance between the apex of the cornea and the convex lens closing the system off. However, the error would be minimal:

"At first sight indeed, the accommodation appears to be somewhat less, and only able to bring the eye from the state fitted for parallel rays (9) *to a focus at five inches distance; and this made me once imagine, that the cornea might have some slight effect in the natural state; but, considering that the* ***artificial cornea*** *was about a tenth of an inch before the place of the natural cornea, I calculated the effect of the difference, and found it exactly sufficient to account for the diminution of the range of vision. I cannot ascertain the distance of the glass lens from the cornea to the hundredth of an inch; but the error cannot be much greater, and it may be on either side."* (10)

1.2 - Variations of the 1807 Edition

(Figure 7 – 8) (Table 7 – 1)

Thomas Young re-edited his communication of the 27th November 1800 in the second volume pages 573 – 606 of his composite work *"A Course of Lectures on natural Philosophy and the mechanical Arts"* that was published in 1807. This re-issue contains minor modifications, which do not modify the meaning of the passage.


THOMAS YOUNG, M.D., F.R.S., &c.,

Vols. I. & II.,

INCLUDING HIS SCIENTIFIC MEMOIRS, &c.

GEORGE PEACOCK, D.D.,

VOLUME I.

LONDON:
JOHN MURRAY, ALBEMARLE STREET.
1855.

Figure 7-8

19th century re-issues of Young's "On the Mechanism of the Eye", 1807 in "A course of lecture on natural philosophy and the Mechanical Art" Vol 2, V, 573-606 & plates, 1855 in "Miscellaneous Works of late Thomas Young including his scientific Memoires", p 12-63 & plate II, fig 10 - 18

6. This optometer is described in the second paragraph of the memoir.
7. Young was affected by an inverse astigmatism of the crystalline lens.
8. Young 1801, p. 58.9. That is to say, infinite.
10. Young 1801, p. 59.

An other re-issue appears in 1855, with the wording of the original 1801 text, in "*Miscellaneous Works of late Thomas Young including his scientific Memoires*" pages 12 – 63. (11)

(Table 7 – 1)
Comparison of the original text of Thomas Young, "On the mechanism of the eye" (Philosophical Transactions of the Royal Society of London) (1801) with the re-edition (A Course of Lecture on natural Philosophy and the mechanical Arts) of 1807.

Text	Original text (1801, p. 57) I drop into a little water, nearly cold, till it is three-fourths full, and then apply it to my eye, so that the cornea enters half way into the socket, and is everywhere in contact with the water	Re-edition (1807, p. 285) I dropt into the socket a little water, nearly cold, till it is three fourths full, and then apply it to my eye, so that the cornea enters half way into it, and is everywhere in contact with the water.
Figure	13, plate III	77, plate IX

11. Reprints are also available:
- *A course of lecture on natural philosophy (1807), reprint London 1971.*
- *Miscellaneous works (3 vol), reprint London 1972.*

2 - Discussion

Young thus utilizes for his experiment the principle of neutralization of corneal dioptric power by a liquid. The set-up of a lens fixed in a water-filled metal cylinder is often compared to the tube described by *Descartes* and is sometimes considered as a model for a hydrodiascope or contact lens. In order to judge the reasonableness or otherwise of these assertions, I propose my own personal critical study of the experimental conditions: the horizontal positioning of the instrument, its uncertain closing off, optical properties, suitability for achieving neutralization of corneal dioptric power and replacement by a new optical surface.

Thus, I will describe the following aspects in logical order:

- the location of the passage on corneal neutralization in *Young*'s work,
- the role which *Young* attributes to the experiment of corneal diopter neutralization,
- the potential connection to be determined between *Young*'s experiment with the hydrodiascopes and contact lenses,
- the interpretations that were provided by the historians of *Young*'s experiment.

2.1 - The Experiment on Neutralization of Corneal Dioptric Power in the Context of *Young*'s Lecture of 27th November 1800

To position the description of the corneal refractive power neutralization experiment by a contact device within the context of the lecture he gave on 27th November 1800 would require citation of *Young*'s entire work, of which the volume is enormous and the consistency dense (12). *Young* recalled his principal themes at the end of his communication, as follows:

"***First***, *the determination of the refractive power of a variable medium, and its application to the constitution of the crystalline lens.*
Secondly, *the construction of an instrument for ascertaining, upon inspection, the exact focal distance of every eye, and the remedy for its imperfections.*
Thirdly, *to show the accurate adjustment of every part of the eye, for seeing with distinctness the greatest possible extent of objects at the same instant.*
Fourthly, *to measure the collective dispersion of coloured rays in the eye.*
Fifthly, *by immersing the eye in water, to demonstrate that its accommodation does not depend on any change in the curvature of the cornea.*
Sixthly, *by confining the eye at the extremities of its axis, to prove that no material alteration of its length can take place.*
Seventhly, *to examine what inference can de drawn from the experiments hitherto made on persons deprived of the lens; to pursue the inquiry, on the principles suggested by Dr Porterfield; and to confirm his opinion of the utter inability of such persons to change the refractive state of the organ.*

12. Hirschberg made an exhaustive study (1911, XXIII, § 460, p. 452-466).

***Eighthly,** to deduce, from the aberration of the lateral rays, a decisive argument in favour of a change in the figure of the crystalline; to ascertain, from the quantity of this aberration, the form into which the lens appears to be thrown in my own eye, and the mode by which the change must be produced in that of every other person. And I flatter myself, that I shall not be deemed too precipitate, in denominating this series of experiments satisfactorily demonstrative."* (13)

Young describes, amongst other things, the following:

- the quantification of refraction,
- the construction of an instrument, the optometer, which is based on *Scheiner*'s experiment,
- the demonstration that accommodation does not depend on modifications of the curvature of the cornea or the length of the globe,
- the measurement of the corneal and scleral parameters of his own eye,
- a new theory of color vision.

2.1.1 - Innovations made by Young

Young bases his arguments on experiments and experimental set-ups. The apparatus, which, in a modern laboratory, is considered to be commonplace, was practically non-existent in his era. Little by little, researchers continued the inventing of instruments capable of measuring qualitative observations. *Young* had understood that experiment and quantification are the surest essentials for the discovery of consistent correlations in all domains of research linked to the Sciences. Let us recall several particularly striking examples from the innovations of *Young* in physiological optics: the description of an optometer, the quantification of accommodation by the crystalline lens, neutralization of corneal refractive power and the measurement of the ocular parameters.

2.1.2 - Young's Optometer and Scheiner's Experiment

Young has given his seal of approval in using an application of *Scheiner's* experiment in his optometer. He constructed an apparatus consisting of a screen, and provided with two fine vertical slits, each with the dimension of the pupil and intended to be held in front of the eye and by means of a horizontal bar held in front of the eye. This bar is seen as two lines crossing at the anterior focal point of the eye. This crossing corresponds with the end-point for the moment of change from diplopia to single vision. The measurement of this end-point is achieved by a precise measuring system consisting of an ivory band provided with divisions. A form of abacus converts the observed measurements into corrective lens power for myopes and hyperopes. As a pioneer in ophthalmometry, *Young* expresses, as *La Hire* had previously attempted, an error of refraction by means of the focusing of the corrective lens necessary to obtain emmetropia.

13. Young 1801, p. 82-83.

We should recall that the experiment performed by *Scheiner* (1619) and carrying his name, was based on a card pierced by two needle holes at a distance from each other less than the diameter of the pupil. In looking through the holes of this card, held up to the eye, at a well-illuminated needle, one looks for the distance at which the needle doubles. *Scheiner* did not provide any explanation for his observation. There are several similar descriptions, but without valid explanation, in folios 2 verso, 4 verso, and 9 recto of Manuscript D of *Leonardo da Vinci* (14). *La Hire* had also carried out this measurement and had observed that there existed a correlation between the position of the point of exchange of the images perceived and the refraction of the eye. He deduced there from that it was possible to measure the refraction and to express it as the distance of the anterior focal point from the eye. He interposed corrective lenses, whose power he expressed in a similar fashion. Finally, to prove the validity of his technique, he repeated the measurement on an artificial eye (15). Several years later, *William Porterfield* (1737) carried out more detailed measurements and constructed an apparatus for these measurements that he designated as an *optometer*, and he used this instrument to measure the power of accommodation (16).

2.1.3 - Quantification of Accommodation by the Crystalline Lens

By combining neutralization of corneal refractive power by means of his contact device with the optometer, *Young* demonstrates that accommodation is a phenomenon of the crystalline lens. He takes the same opportunity to quantify the amplitude of accommodation. By these measurements, he rules out modifications of the axial length and corneal curvature at the time of accommodation. He observes that the height of images reflected from the same object (measured as the distance between two candle flames) does not change with accommodation and that accommodation is preserved after neutralization of the corneal refractive power by submerging the cornea in the water-filled container.

Young arrives therefore at the conclusion that accommodation is due to changes in the curvature of the crystalline lens. He positively eliminates hypotheses put forward by his predecessors:

- that accommodation would require no modification of the ocular dioptric apparatus (as *La Hire* had previously believed in 1685),
- that pupillary motility was responsible for accommodation (as *La Hire* had believed in 1685) and that accommodation would be provoked by modifications of corneal curvature (according to *Home* in 1795),
- that the crystalline lens would displace itself towards the retina at the time of accommodation (according to *Kepler*, 1611 and *Porterfield*, 1759),
- that the extrinsic muscles of the eye would cause the axis of the globe to elongate and would thus produce accommodation.

14. For example in Leonardo da Vinci: "For this experiment, let us make a perforation, which may be about the size of a millet seed, with a large needle in a sheet of paper. Let us place this sheet in front of the pupil of the eye at a distance of one-third or one-fourth of a 'braccia' and you will see that through such a hole the air will look inverted." (Manuscript D folio 4 verso).
15. See Chapter IV: Philippe de La Hire's Ocular Contact.
16. William Porterfield, 1759. See also the study done on Porterfield (1696 - 1771) by Levene 1977, p. 1 - 15.

2.1.4 - NEUTRALIZATION OF CORNEAL DIOPTRIC POWER
(Figure 7 – 8)

By means of the improvised contact device derived from a botanical microscope ocular (eyepiece), *Young* did not research the correction of a refractive error, but rather the neutralization of corneal dioptric power in order to eliminate the cornea from a hypothetical active role in accommodation.

This is an ingenious idea and experimental model, not only for the purpose of neutralizing corneal refractive power by means of the liquid poured into the cylinder supporting the microscopic eyepiece, but also to replace the neutralized cornea by a new lens, or *'artificial cornea'*, i.e. the lens from eyepiece of the microscope. The conclusions that *Young* draws from this experiment are, indeed, an approximation, because he admitted not knowing the depth of protrusion of the corneal apex into the open end of the microscopic eyepiece cylinder and therefore the distance separating this point from the microscope lens. This, however, was not the aim of his experiment.

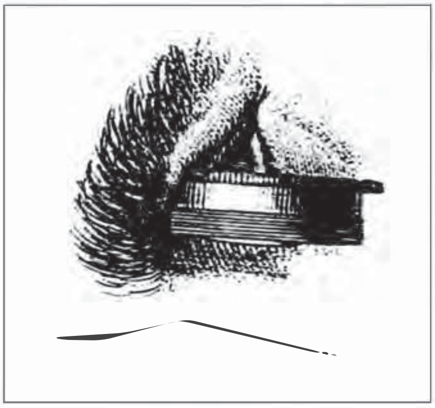


Figure 7-8

Thomas Young: "On the Mechanism of the Eye". (Philosophical Transactions of the Royal Society of London, 1801). Figure 13 of the plate III illustrates the experiment of ocular immersion in water filled cylinder (tube), taken from the eyepiece of a microscope. Note that, on this plate, the cylindrical tube is placed downwards and that the direction of gaze of the person doing the experiment is also directed downwards. This position of the cylindrical tube prevents the water, with which it was filled to three quarters, from running out, without recourse to sealing it. The eye is opposite the half of the surface area of the opening of the cylindrical tube, the border of which is up against the orbit. The positioning of the cylinder, as represented in plate III, is very important for the rigorous interpretation of Young's experiment.

2.1.5 - MEASUREMENT OF OCULAR PARAMETERS

Young's paper presents other points of interest, particularly the description of an original technique of measurement of ocular parameters. With two keys fixed to the legs of a pair of dividers (calipers), *Young* attempts to measure the transverse diameter of his own eye:

" *For measuring the diameters, I fix a small key on each point of a pair of calipers, and I can venture to bring the rings into immediate contact with the sclerotica. The transverse diameter is externally 98 hundredth of an inch.*"(17)

The optic axis is measured by the same means, under more acrobatic conditions:

"*To find the axis, I turn the eye as much inwards as possible, and press one of the keys close to the sclerotica, at the external angle, till it arrives at the spot where the spectrum formed by its pressure coincides with the direction of the visual axis, and, looking in a glass, I bring the other key to the cornea. The optical axis of the eye, making allowance of three hundredth for the coats, is thus found to be 91 hundredths of an inch, from the external*

17. Young 1801, p. 38. Young finds a transverse diameter of 23.98 mm. One should compare this dimension with the currently accepted one of 24.13 mm (average of between 23 and 25 mm according to various authors, see Duke-Elder 1961, II, p. 80).

surface of the cornea to the retina. With an eye less prominent, this method might not have succeeded." (18)

To continue, *Young* described several more methods of measurement for the corneal curvature based on the determination of the distance separating the corneal reflection of two luminous points, according to the principle used later for the keratometer. These measurements serve, as the socket for corneal immersion, to demonstrate that the cornea remains unchanged at the time of accommodation at near vision. *Young*, on the same basis as *Scheiner* and before *Purkinje*, thus laid the foundation for keratometry that lead subsequently to the ophthalmometers of *Helmholtz* and *Javal-Schiotz*. (19)

2.2 - Interpretations of the Neutralization of Corneal Dioptric Power

There is no doubt that the instrument utilized by *Young* is a system of neutralization of the corneal dioptric power because:

a) it neutralizes the anterior surface of the cornea by contact with a liquid,
b) it replaces the neutralized corneal dioptric power by a new optical element.

There are, however, differences of interpretation between different authors on the realization of the contact of the container and therefore of the extent of the immersion of the eye. The passage: *[...] **securing** its edges with wax, [...] and then apply it to my eye, so that the cornea enters **half way** into the socket, and is every where in contact with the water"*, is the object of controversies and polemics where two hypotheses are opposed, each based on divergences of interpretation and translation.

2.2.1 - The 'traditional' Interpretation

The majority of authors consider that the container filled with water is **fixed** with wax directly to the eye (cornea or sclera). The cornea would be submerged and penetrate **halfway** into the depth of the container and thus be wholly in contact with water.

Those people who follow this interpretation refer to a vocabulary interpretation according to which:

*"**securing**"* can mean 'to fix', in order to cause the container to adhere to the eye,
"enters half way" means that the eye penetrates half-way (i.e. deeply) inside the container

18. Young 1801, p. 38. This has to do with the first-ever measurement of the optic axis of an eye in vivo. The measurement of 23.11 mm which was found should be compared to the currently accepted average for an emmetropic eye of 22.12 mm (with extremes of 19.71 mm for the hyperopic eye and 34.77 mm for the myopic eye (see Duke-Elder 1961, II, p. 81). According to Hirschberg, Young would have been slightly myopic.
19. Helmholtz 1855, Javal 1880. The reader will benefit by referring to Hirschberg § 1035, "Das Ophthalmometer" for the history of the ophthalmometer.

2.2 2 - Objections to the 'traditional' Interpretation
(Figure 7 – 9)

Objections to this interpretation are based on the examination of figure 13 of plate III and its legend ***"The method of applying a lens with water to the cornea".***

According to the legend to figure 13, this must not only illustrate, but also explain the manner *('the method')* of application of the device. Moreover, one can observe in this figure several aspects, which puts in question the 'traditional' interpretation:

- the cylindrical tube is placed **downwards,**
- the head of the experimenter leans over the water container; this inclined position is underlined by the horizontal side view of the bridge of the nose,
- no part of the sketch indicates the utilization of wax to 'fix' the container to the eye. The interpretation of the term **'securing'** in the sense of 'fixing' is controversial and we should have recourse to the second meaning of the term, that of 'protecting', or of 'placing in a shelter or out of danger'. According to this interpretation, *Young* would have coated the open rim of the cylinder with wax in order to protect himself and prevent possible injuries by contact with the sharp rim of the open end of the cylinder (20),
- no part of the sketch demonstrates a sealing with wax of the space between the open rim of the microscopic eyepiece and the eye. According to the diagram, the container is far from the eye and the only possible contact would be situated at the level of the upper eyelid,
- the diameter of the cylinder is obviously larger than that of the eye. The cylinder covers the upper and lower eyelids as well as the orbital skin surface from its upper to its lower border,
- in the diagram, the eye is placed opposite, approximately **half** of the container. The other half of the container faces the skin. The interpretation of the expression, *"the cornea enters **half way** into the socket"* could therefore indicate that the cornea is only opposite of the half of the opening of the microscopic eyepiece cylinder. (21)

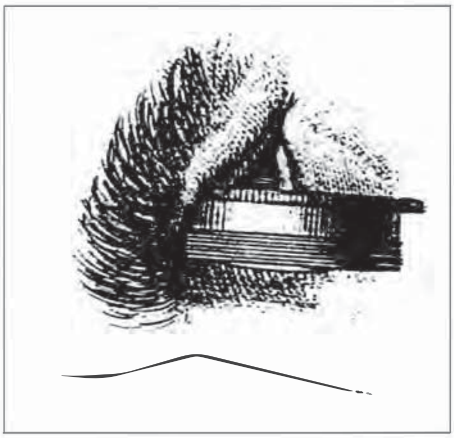


Figure 7-9

Thomas Young: "On the Mechanism of the Eye", in Philosophical Transactions of the Royal Society of London, 1801, Enlargement of figure 13 of plate III.
The legend: "The method of applying a lens with water to the cornea" indicates that the diagram represents the experimental set-up and the position of the head corresponding to the mode of carrying out the experimental application of a eye-bath of water consisting of a cylindrical tube of the eyepiece (ocular) of a botanical microscope.
It should be noted that the tube is placed above the head. The person performing the experiment inclines his head, directs his gaze downwards and thus submerges his eye in the water bath contained in the socket of the microscope eyepiece. The structure covers the eyelids and borders on the skin of the orbit.
The open side of the tube does not touch the globe. Its rim is covered with wax, to avoid injuries. The wax's purpose is not to ensure a watertight seal between microscope tube and the eye.

20. Tscherning (1894, p. 165) also retained this interpretation: " après avoir enduit les bords du tube de cire " (after having sealed the sides of the tube with wax) and by Rohr (1923, p. 127): " ich sicherte seinen Rand mit Wachs. " (I secured its rim with wax.)
21. The expression "half way" can also mean 'more or less half' or 'approximately half'.

Taking account of these various aspects that are based on figure 13 of plate III and on its legend, it seems logical to assume that *Young* carried out the '*neutralization container*' experiment according to the following procedure:

- he removed the hollow cylindrical metal tube, i.e. the botanical microscope eyepiece including convex lens (ocular). The diameter of the cylindrical tube is much greater than the inter-palpebral aperture (by about a factor of two),
- he covered the open border of the cylinder with wax,
- he filled the cylinder with water and maintained it in position to prevent it from running out,
- he inclined his head just at the moment when the cornea was submerged in water,
- at this moment, the hole of the cylinder was half inclined to his eye, half facing surrounding cutaneous surfaces, i.e. lids and orbit.

The divergences of opinion about the execution of the experiment of the container, whether it is performed with a cylinder fixed to the eye or that the eye is immersed in the cylinder, do not change the purpose of the experiment. The water contained in the metal cylinder neutralizes the two dioptric surfaces in contact with it: that of the anterior cornea and that of the posterior surface of the microscope ocular. These two dioptric powers neutralized by the water are replaced by the single dioptric power of the external surface of the ocular.

Thus is formed an optical system that is reminiscent of the *Descartes'* tube but in reduced size and in other position. *Young*'s objective was quite different; he was researching the neutralization of corneal dioptric power and not an eventual magnification effect, as required by *Descartes*. One should note that *Young* uses the term "*the artificial cornea*" to signify the anterior lens surface, which goes to show that he wished to replace the surface of the neutralized cornea of his eye by the anterior surface of the lens (the ocular) fixed in the cylindrical tube of the microscope eyepiece.

Be that as it may, one must admire *Young's* experiment on his own eye, the more so that no anesthetic was available at this era with added the risk of ocular injury with the set-up as described is significant, even with the wax coating on the outer wall of the cylinder border.

3 - Thomas Young, Neutralization of Corneal Dioptric Power and Contact Lenses

In comparing the criteria of the corneal immersion instrument of *Young* with those of corneal diopter neutralization devices including contact lenses, one comes to the following conclusions:

It is true that *Young* not only described, but also carried out:

- voluntary corneal immersion in a liquid with intent to neutralize optically the corneal dioptric power,
- replacement of the dioptric power of the neutralized cornea by a new refracting surface,
- consisting of the external lens surface, to which surface he gave the name *"artificial cornea"*.

It is untrue to equate the water-filled cylinder used by *Young* to one of the hydrodiascopes or to a contact lens, because *Young's* device:

- did not have the optical correction of a refractive error as its purpose, but rather the neutralization of corneal power in order to research the part of the eye responsible for accommodation,
- was not placed underneath the eyelids as are contact lenses,
- was not placed against the skin surface as were the hydrodiascopes,
- had neither contact with the eye, nor with the skin,
- was not designed to remain for an extended time in contact with the eye,
- permitted, if one accepts figure 13 of plate 13, a simple immersion of the corneal apex in the liquid, without contact with the eye or the skin with any part of the device whatever.

One must admire the courage and expertise of *Young*, who had the idea of this corneal immersion experiment and carried it out on himself without the aid of a local anesthetic. It is certain that he understood the principle of the neutralization of corneal dioptric power and the replacement of the cornea with another power. He did not have the intention to utilize his device for the correction of a refractive error in the manner of a hydrodiascopes or a contact lens, but for optical neutralization of the cornea.

4 - Short History of Citations, Omissions and Misinterpretations

The first citation of *Young* in connection with neutralization of corneal dioptric power seems to have been made in 1938, by *Mann:*

"The essential idea of abolishing a faulty cornea by substituting an artificial and accurate one was promulgated by Thomas Young, who in 1801 published in the Philosophical Transactions an account of an apparatus, afterwards called a hydrodiascopes, the object of which was to abolish the action of the cornea as a refracting medium by placing in front of it a lens of known power separated from it by a layer of water of known thickness. It was a small home-made affair, and Young describes how he used a little lens from an old botanical microscope and stuck it in a tube about a quarter of an inch long with wax, then filled the tube with cold water and, smoothing the edges with wax, applied it to his own eye." (22)

This summary is made up of errors by attributing a vertical position to the device (*'placing in front')*, of letting the reader understand that it was *'applied to his [Young's] eye'*, and to present *Young*'s tube as a hydrodiascope prototype. These errors were often to be repeated, e.g.:

"Thomas Young in 1801 described the hydrodiascopes, the precursor of the scleral lens with intermediary fluid." (23)

And more recently:

"By 1801, Thomas Young had experimented with convex lenses sealed with wax into a smaller collar that was filled with water and put before the eye." (24)

Young is besides not always cited among the pioneers of contact devices and few authors have failed to go back to original source material. So it is, that with the passing of the years, copies and translations have deviated from the idea of corneal dioptric power neutralization by *Young* towards more fanciful and unreliable interpretations. The most often repeated error consists of rotating the illustration in order to give the representation of a contact device placed **in front** of the eye of a head positioned vertically and to liken the device in this way to *"a little Descartes' tube"*.

22. *Mann 1938, p. 109.*
23. *Cochet et al. 1969, p. 233.*
24. *Rubin 1996, p. S102.*

4.1 - Rotation of Figure 13

(Figure 7 – 10)

Nearly all historians utilize *Young*'s figure 13 in a modified form and with an incorrect rotation of 90 degrees. Whereas the original depicts an eye **looking down and immersed** into water contained in the cylindrical metal cylinder of a microscope eyepiece, the citations indicate a horizontal direction of regard, the tube being positioned in the manner of the *Descartes*' tube, the *Czermak* orthoscopes, the *Lohnstein* and *Siegrist* hydrodiascopes or a contact lens. Even English-speaking circles, notwithstanding their easier access to the documents of *Young*, do repeat these errors.

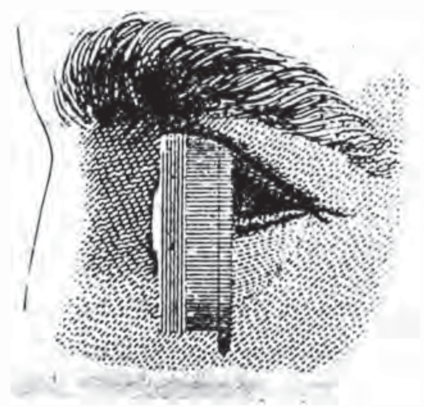


Figure 12.4. Thomas Young's experiment of corneal neutralization

Figure 7-10

Incorrect extrapolation of Young's diagram: After rotation of the diagram, the cylinder appears in front of the eye, like a contact lens.

The authors suppose, erroneously, that the water is retained by a wax strip (not represented on the drawing!), which filled the space between the rim of the socket and the eye and/or the skin. (Levene 1977, p. 304, fig. 12.4)

4.2 - Young's 'Presbyopia'

For the last twenty years there has been the erroneous claim that the contact device equipped with a convergent lens would have made *Young* myopic, whereas the description is unambiguously in favor of '*presbyopia*', as hyperopia was called at the period of time under consideration:

"he placed it against his eye, making his vision highly myopic" (25)

and:

"He described with precision how he became artificially myopic and even determined his error of refraction."

« Er beschreibt ausführlich, wie er hierdurch künstlich kurzsichtig wurde und berechnete sogar die fehlende Brechkraft» (26)

4.3 - The lengthened Contact Lens

For certain authors, *Young*'s device would be a '*lengthened contact lens*':

"The present-day contact lens is none other than a Young's container, in which the bed of fluid that separates the cornea from the lens is reduced from 25 mm, which it had in the primitive instrument, to the thickness of a capillary layer, and in which the lens is, in principle, a meniscus with almost parallel surfaces."

25. Ruben 1975, p. 1 and 1978, p. 1.
26. Roth 1978, p. 29.

It would serve to eliminate corneal refractive errors and to replace these with a regular ground lens:

"His concept was the simple expedient of eliminating the cornea with its frequently irregular optical properties from the dioptric system of the eye and substituting for it a regular ground lens." (28)

4.4 - The Lens would be placed against the Cornea

Another unjustified interpretation would require that the metal microscope eyepiece cylinder or, for certain authors, a convex lens may be placed directly on the cornea, where it would eventually be sealed by a wax cushion:

"He put water into a small contact lens with a wax collar and placed it against his eye."(29)

and:

« Il remplit son 'Hydrodiascope' aux trois quarts d'eau et l'applique à sa propre cornée. » (30)

"He fills his 'hydrodiascope' three quarters with water and applies it to his own cornea."

Some historians make no comment on the ocular contact of *Young* or, as with *Levene*, do not take the risk of attributing to him the priority of the hydrodiascope or contact lenses. *Levene* comments that *Young* did not wish to correct an error of refraction, but used this as an investigative device to measure the ocular parameters and research the part of the eye responsible for accommodation. If he achieved corneal neutralization, it was with an intention quite different from that of a contact device or contact lenses.

4.5 - The Explanation for some Misinterpretations

(*Table 7 – 2*)

It is always embarrassing to search out the misinterpretations of historians. It seems to me that an explanation of these mistakes can be found in a cascade of translations starting from citations. *Helmholtz* in his treatise of 1864 translated the passage of *Young* for the first time into German. In 1924, at the time of an English translation of this treatise by *Southall* the latter provided a version not conforming to the text of *Young*. This re-translation served subsequently as reference for certain historians neglecting to verify the original (31). Thus, the original passage *"the cornea enters half way into the socket"* was retranslated as *"the*

27. Haas 1937, p. 63. Mackie in Duke-Elder (1970) also shared this opinion, likewise Baron (1981).
28. Mackie in Duke-Elder, 1970, p. 713.
29. Ruben 1975, p. 1 and Ruben 1978, p. 1, translated in German language by Roth: " Er füllte Wasser in kleine konvexe Linsen mit Wachskragen, drückte sie gegen sein Auge und wurde so Myop. "
30. Lumbroso 1977, p. 16.
31. Helmholtz, translated by J.P.C. Southall, published by the Optical Society of America 1924, p. 153. Alpern notably (1948, p. 198) and Fischer (1996, p. 370) utilized this corrupted text.

(Table 7 – 2)
Comparison of the original text of Young (1801) with the text after it had been corrupted by a first translation into German language by Helmholtz (1864, 1904) followed by a re-translation into English language by Southall (1924).

ORIGINAL TEXT (YOUNG 1801, P.57)	**CORRUPTED TEXT (SOUTHALL 1924, P.153)**
I take out of a small botanical microscope, a double convex lens, of eight-tenths radius and focal distance, fixed in a socket one-fifth of an inch in depth; securing its edges with wax, I drop into it a little water, nearly cold, till it is three-fourth full, and then apply it to my eye, so that the cornea enters half way into the socket, and is every where in contact with the water.	From a small botanical microscope I take a double convex lens having a radius and focal length of 0.8 inch which is fastened in a socket one-fifth of an inch deep; securing its edges with wax, I drop into it a little moderately cold water till it is three-fourths full, and then apply it to my eye, so that the cornea projects into the socket and its everywhere in contact with the water.

cornea projects into the socket", that would emphasize the penetration of the cornea into the microscope eyepiece cylinder and not the covering by the cornea of half of the surface area of the cylinder opening.

These errors are regrettable, for they distort the meaning of the text of *Young* without insisting on the fact that the experimental model utilized for the study of accommodation assures the neutralization of corneal refractive power and even the replacement of the neutralized dioptric power by a new optical surface, designated as an '*artificial cornea*'.

One cannot liken this experimental set-up both to a contact lens, even one that has become elongated, as certain authors have believed and certainly not to a hydrodiascope. These mistaken opinions are due to instances of neglect of the analysis of figure 13 of plate III, with particular reference to its incorrect rotation by 90° and, not least, to errors induced by successive translations of *Young's* original text.

Appendix

Transcription of:

Thomas Young
On the Mechanism of the Eye

Philosophical Transactions of the Royal Society, 91, 23-88, 1801

Citation 1
(§ VIII, Philosophical Transactions, p. 57 & 58, 1801)

But a much more accurate and decisive experiment remains. I take out of a small botanical microscope, a double convex lens, of eight-tenths radius and focal distance, fixed in a socket one-fifth of an inch in depth; securing its edges with wax, I drop into it a little water, nearly cold, till it is three-fourths full, and then apply it to my eye, so that the cornea enters half way into the socket, and is every where in contact with the water. (Plate III Fig. 13)

My eye immediately becomes presbyopic, and the refractive power of the lens, which is reduced by the water to a focal length of about 16 tenths, (Cor. 5. Prop. IV.) is not sufficient to supply the place of the cornea, rendered inefficacious by the intervention of the water; but the addition of another lens, of five inches and a half focus, restores my eye to its natural state, and somewhat more.

I then apply the optometer, and I find the same inequality in the horizontal and vertical refractions as without the water; and I have, in both directions, a power of accommodation equivalent to a focal length of four inches, as before.

At first sight indeed, the accommodation appears to be somewhat less, and only able to bring the eye from the state fitted for parallel rays to a focus at five inches distance; and this made me once imagine, that the cornea might have some slight effect in the natural state; but, considering that the **artificial cornea** was about a tenth of an inch before the place of the natural cornea, I calculated the effect of this difference, and found it exactly sufficient to account for the diminution of the range of vision. I cannot ascertain the distance of the glass lens from the cornea to the hundredth of an inch; but the error cannot be much greater, and it may be on either side.

Citation 2
(§ XII, Philosophical Transactions, p. 82 & 83, 1801)

XII. I shall now finally recapitulate the principal objects and results of the investigation which I have taken the liberty of detailing so fully to the Royal Society.

First, the determination of the refractive power of a variable medium, and its application to the constitution of the crystalline lens.

Secondly, the construction of an instrument for ascertaining, upon inspection, the exact focal distance of every eye, and the remedy for its imperfections.

Thirdly, to show the accurate adjustment of every part of the eye, for seeing with distinctness the greatest possible extent of objects at the same instant.

Fourthly, to measure the collective dispersion of coloured rays in the eye.

Fifthly, by immersing the eye in water, to demonstrate that its accommodation does not depend on any change in the curvature of the cornea.

Sixthly, by confining the eye at the extremities of its axis, to prove that no material alteration of its length can take place.

Seventhly, to examine what inference can be drawn from the experiments hitherto made on persons deprived of the lens; to pursue the inquiry, on the principles suggested by Dr. Porterfield; and to confirm his opinion of the utter inability, of such persons to change the refractive state of the organ.

Eighthly, to deduce, from the aberration of the lateral rays, a decisive argument in favour of a change in the figure of the crystalline; to ascertains, from the quantity of this aberration, the form into which the lens appears to be thrown in my own eye, and the mode by which the change must be produced in that of every other person.

And I flatter myself, that I shall not be deemed too precipitate, in denominating this series of experiments satisfactorily demonstrative.

Citation 3
(§ VI, Philosophical Transactions, pages 38 & 39, 1801)

Being convinced of the advantage of making every observation with as little assistance as possible, I have endeavoured to confine most of my experiments to my own eyes; and I shall, in general, ground my calculations on the supposition of an eye nearly similar to my own. I shall therefore first endeavour to ascertain all its dimensions, and all its faculties.

For measuring the diameters, I fix a small key on each point of a pair of compasses, and I can venture to bring the rings into immediate contact with the sclerotica. The transverse diameter is externally 98 hundredths of an inch.

To find the axis, I turn the eye as much inwards as possible, and press one of the keys close to the sclerotica, at the external angle, till it arrives at the spot where the spectrum formed by its pressure coincides with the direction of the visual axis, and, looking in a glass, I bring the other key to the cornea. The optical axis of the eye, making allowance of three hundredths for the coats, is thus found to be 91 hundredths of an inch, from the external surface of the cornea to the retina. With an eye less prominent, this method might not have succeeded.

The vertical diameter, or rather chord, of the cornea, is 45 hundredths: its versed sine 11 hundredths. To ascertain the versed sine, I looked with the right eye at the image of the left, in a small speculum held close to the nose, while the left eye was so averted that the margin of the cornea appeared as a straight line, and compared the projection of the cornea with the image of a cancelled scale held in a proper direction behind the left eye, and close to the left temple. The horizontal chord of the cornea is nearly 49 hundredths.

Hence the radius of the cornea is 31 hundredths. It may be thought that I assign too great a convexity to the cornea; but I have corrected it by a number of concurrent observations, which will be enumerated hereafter.

The eye being directed towards its image, the projection of the margin of the sclerotica is 22 hundredths from the margin of the cornea, towards the external angle, and 27 towards the internal angle of the eye: so that the cornea has an eccentricity of one fortieth of an inch, with respect to the section of the eye perpendicular to the visual axis.

Citation 4
(§ VIII, Philosphical Transactions, p. 55 & 56, 1801)

Room was however still left for a repetition of the experiments; and I began with an apparatus nearly resembling that which Mr. Home has described. I had an excellent achromatic microscope, made by Mr. Ramsden for my friend Mr. John Ellis, of five inches focal length, magnifying about 20 times. To this I adapted a cancelladed micrometer, in the focus of the eye not employed in looking through the microscope: it was a large card, divided by horizontal and vertical lines into fortieths of an inch. When the image in the microscope was compared with this scale, care was taken to place the head so that the relative motion of the images on the micrometer, caused by the unsteadiness of the optic axis, should always be in the direction of the horizontal lines, and that there could be no error, from this motion, in the dimensions of the image taken vertically. I placed two candles so as to exhibit images in a vertical position in the eye of Mr. König, who had the goodness to assist me; and, having brought them into the field of the microscope, where they occupied 35 of the small divisions, I desired him to fix his eye on objects at different distances in the same direction: but I could not perceive the least variation in the distance of the images.

Finding a considerable difficulty in a proper adjustment of the microscope, and being able to depend on my naked eye in measuring distances, without an error of one 500the of an inch, I determined to make a similar experiment without any magnifying power. I constructed a divided eye-glass of two portions of a lens, so small, that they passed between two images reflected from my own eye; and, looking in a glass, I brought the apparent places of the images to coincide, and then made the change requisite for viewing nearer objects: but the images still coincided. Neither could I observe any change in the images reflected from the other eye, where they could be viewed with greater convenience, as they did not interfere with the eyeglass. But, not being at that time aware of the perfect sympathy of the eyes, I thought it most certain to confine my observation to the one with which I saw. I must remark that, by a little habit, I have acquired a very ready command over the accommodation of my eye, so as to be able to view an object with attention, without adjusting my eye to its distance.

I also stretched two threads, a little inclined to each other, across a ring, and divided them by spots of ink into equal spaces. I then fixed the ring, applied my eye close behind it, and placed two candles in proper situations before me, and a third on one side, to illuminate the threads. Then, setting a small looking-glass, first at four inches distance, and next at two, I looked at the images reflected in it, and observed at what part of the threads they exactly reached across in each case; and with the same result as before.

I next fixed the cancelladed micrometer at a proper distance, illuminated it strongly, and viewed it through a pin-hole, by which means it became distinct in every state of the eye; and, looking with the other eye into a small glass, I compared the image with the micrometer, in the manner already described. I then changed the focal distance of the eye, so that the lucid points appeared to spread into surfaces, from being too remote for perfect vision; and I noted on the scale, the distance of their centres; but that distance was invariable.

Lastly, I drew a diagonal scale, with a diamond, on a looking-glass, (Plate III. Fig. 12.) and brought the images into contact with the lines of the scale. [...].