Simple method of determining the axial length of the eye

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The x-ray method of determining the axial length of the eye employed by Sorsby (Rushton, 1938; Sorsby and O'Connor, 1945; Duke-Elder and Abrams, 1970) has been superseded by ultrasonic techniques. Although the latter have attained considerable accuracy they can hardly be used for routine clinical purposes, particularly in children. The following method was developed to fulfill this need.

If the globe can be considered as a sphere rotating about a fixed point in a cup of orbital fat the movement of a point on the cornea during rotation of the globe through a known angle will be directly related to the radius of rotation. In Fig. 1 the eye rotates through an angle $\alpha$ about C to fix an object first at A and then at B. If the distance between X and Y can be measured and the angle $\alpha$ is known the radius of the globe CX or CY can be calculated thus:

$$CX = \frac{XY}{2 \times \sin \frac{\alpha}{2}}$$

There are two important assumptions which require further examination. First, can the eye be considered to be spherical? This may be assumed to be almost correct for a normal eye. Although the radius of curvature of the cornea is less than the radius of curvature of the globe, the apex of the cornea is said to coincide with the circumference of the globe (Duke-Elder and Wybar, 1970), so that measurement of the radius from a point near the centre of the cornea to the centre of the globe will be equal to the radius of the globe. Doubling this measurement will give the axial length. In the case of a highly myopic eye, in which the globe is not enlarged symetrically but which is elongated in its antero-posterior axis, rotation will take place about the centre of curvature of the posterior segment, and the distance from this point to the apex of the cornea will be greater than the radius of the posterior segment. A measurement derived from movement of a point on the apex of the cornea will not, therefore, give the radius of the posterior segment of such an eye, and doubling this measurement will give an overestimate of the total length. If, however, the method is used to estimate the progressive increase in length of an individual eye the increase in the distance from the apex of the cornea to the centre of rotation of the posterior segment will indicate the elongation of the eye. Although therefore such an estimation of the axial length may be inaccurate in a highly myopic eye the method will still give relevant information concerning the change in antero-posterior length in any individual eye.

The second assumption is that the globe rotates about a fixed point. The centre of ocular rotation in the horizontal plane was carefully measured by Park and Park (1933), who found from measurements on 14 subjects that as the eye rotated from $39^\circ$ nasally to $38^\circ$ temporally the centre of rotation moved along a curve slightly nasal to the visual axis and extending from a point 14.732 mm to a point 12.950 mm behind the cornea. At $4^\circ$ nasally...
the distance from the cornea was 13.918 mm, and
at 3° temporally 13.749 mm. The antero-posterior
movement of the centre of rotation was almost
symmetrical about its position when the eye was
in the primary position. If the centre of rotation is
calculated from a symmetrical position a mean
value would be obtained which, although not from
the exact geometric centre of rotation, would
be comparable from one eye to another.

There are therefore some theoretical objections
to a calculation of the radius of the globe from
observations of the movement of the apex of the
cornea, but as the method is simple it seemed worth
trying in the hope that measurements of clinical
value could be obtained.

It is impossible to visualize the apex of the cornea
for purposes of measurement, and observation of a
small feature such as a blood vessel at the limbus
was found to be difficult. However, if the fixation
points A and B in Fig. 1 are replaced by illuminated
targets in the form of a slit a bright corneal reflex
can be seen and photographed by means of a
camera mounted between A and B. The reflection
of the target lies on the visual axis behind the
cornea and its position depends on the corneal
curvature. It would be possible to measure the
corneal curvature (and hence to determine the
position of the image) by using a keratometer,
but if the targets at A and B are photographed
simultaneously the corneal curvature can be
obtained from the separation of the two images
(A and B in Fig. 1) either by calculation or by
means of a calibration curve obtained by photo-
graphing a series of polished steel balls of known
radius. The latter method is more convenient, as
an allowance can be made for the magnification
of the photographic image and the actual distance
between the two images on the film can be plotted
against corneal curvature.

Method

The apparatus employed is shown diagrammatically in
Fig. 2. The reflex camera, fixation targets, etc., were
mounted on a slit-lamp base placed on an instrument
table. The targets were arranged on an arc, the centre
of curvature of which was the focal point of the camera
lens, and separated by an angle of 45° or 60°. The lens
was an 80 mm Leitz Photar mounted on an extension
tube which contained a small fibre-optics light guide
mounted 94 mm behind and facing the lens. This
provided a fixation spot for the patient during kerato-
metry.

The subject was seated with his head on the head-rest
and instructed to look at the lens of the camera. In
addition to a constant illumination of the test target—
a slit—from a festoon bulb, a small flash tube, was
placed behind each target. The images of the targets
could be accurately focused by moving the instrument
with the joystick of the slit-lamp base, and a photograph
of the cornea was taken with both targets illuminated
by the flash tubes. The subject was then instructed to
look at a red dot in the centre of the left-hand target and
another photograph taken with the flash from this
target. The shutter of the camera was kept open and
the subject viewed a green dot in the centre of the right-
hand target while this flash was fired. The resultant
frame had a photograph of the eye in the two positions
of gaze, and the image of each target appeared separated
by a distance which could be measured and used to
calculate the radius of movement of the reflex. Photo-
graphs of each eye were taken twice.

It was found convenient to place a scale calibrated
in fifths of a millimetre in front of the film plane, so
that an image of the scale was also obtained on the film
and the separation of the reflexes could be read direct
from the negative. So that the background exposure of
the film would be sufficient to show the scale, the shutter
was used in the ‘bulb’ position and kept open for about
5 s. With FP4 film the scale could be seen clearly on
each frame. A switch was provided so that in one
position both flashes were fired simultaneously for
measurement of the corneal radius and in the second
position either flash could be fired by pressing one of
two buttons. This was probably an unnecessary refine-
ment, as even if both flashes were fired with the eye in
the two positions of movement it was easy to see on the
film which of the two flashes was aligned with the optic
axis.

Calculations

Keratometry

Knowing the magnification of the camera (× 1.875), it
was possible to derive the separation of the two images
in millimetres and from this measurement to calculate
the radius of curvature, knowing the actual distance
between the two light sources and their distance from
the cornea.
From a series of tests on steel ball-bearings of known diameter it was found that no serious error was introduced by multiplying the separation in millimetres of the images on the film by a constant factor of 1.62, and this was used for the clinical measurements.

**Radius of movement of globe**

From Fig. 1 it can be seen that the image of targets placed at A and B will lie on the optic axis behind the surface of the cornea. Its position on the optic axis will depend on the curvature of the cornea and the distance between the cornea and the target. If the target is at infinity the image will be at the focal point—that is, halfway between the centre of curvature of the cornea and the corneal surface. In this apparatus the target is not at infinity and, although the position of the image could be calculated, for clinical purposes the narrow slit can be considered as a point source and the calculations simplified by considering it to be at infinity.

The separation of the two images on the film is corrected by the magnification factor (×1.675) and the radius of their movement as the eye moves from one target to the other equals their linear separation in millimetres divided by the sine of the angle of movement (usually 40°). To obtain the radius of the globe the distance of the image from the anterior surface of the cornea has to be added to the radius of movement of the images.

**Results**

To test the method steel balls of known radius from 6.35 to 8.73 mm were mounted on a pivot in such a way that they could be rotated with varying centres of rotation through an angle of 60°. The face of the balls thereby represented the corneas of eyes of different diameter. The radii of rotation were in the range expected in human eyes and varied from 11.35 mm to 15.33 mm, representing axial lengths of 22.7 mm to 30.66 mm.

The results (Table I) showed that there was fairly good agreement between the so-called true radius of rotation and that calculated from the photographs. The 'true radius' consisted of an accurate measurement of the steel ball with a micrometer added to its distance from the centre of rotation of the pivot—normally 5, 6, or 7 mm, although this distance could not be measured so accurately as that of the diameter of the balls. The mean error between the 'true radius' and the measured radius was 0.11 mm (SD 0.11, SE 0.0213).

**Clinical measurements**

Measurements were made on 80 eyes of patients aged 10 or over. As expected, the axial length of eyes with small refractive errors (+2.00 D to -1.00 D) showed no significant correlation with axial length. The mean for male eyes was 27.95 mm and for female eyes 26.33 mm.

<table>
<thead>
<tr>
<th>Table I</th>
<th>Verification of photographic measurements using steel balls of known radii rotated through known angles</th>
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<tbody>
<tr>
<td>Radius of ball (mm)</td>
<td>True radius of movement (mm)</td>
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Mean error 0.11, SD 0.11, SE 0.0213

Fig. 3 shows the refraction of all eyes plotted against their axial length. There is an obvious correlation, and computer analysis gave a correlation coefficient for all eyes of 0.8592. The regression line for axial length on refraction was R = -2.578 + 66.658, where R = refraction in dioptres and A = axial length in millimetres. The correlation for female eyes alone (Fig. 4) was 0.7607 and for male eyes (Fig. 5) 0.8925. If eyes with refractions between +2.00 D and -1.00 D were excluded the correlation coefficient was 0.8739. There was also a correlation between corneal radius and refraction (0.2012 for all eyes) (Table II).

**Discussion**

The axial length of eyes with low refractive errors as measured by this method is about three milli-
Determining the axial length of the eye

- Metres greater than that obtained by X-ray or ultrasonic techniques. The latter techniques measure the distance between the anterior surface of the cornea and the retina, whereas the present method includes the thickness of the choroid and sclera. According to Duke-Elder and Wybar (1970) the choroid is 0.2-0.3 mm thick and the sclera 1.3 mm thick at the posterior pole, so our measurements would be expected to be about 1.5 mm too great. This still leaves 1.5 mm to be accounted for. The calculation of axial length assumes that the apex of the cornea coincides with the circumference of the globe. If, however, this assumption is incorrect and the cornea is a segment of a sphere protruding from the globe the axial length as calculated would be overestimated by the corneal protrusion. Assuming a corneal radius of 7.5 mm, a corneal diameter of 12 mm, and a radius of curvature of the globe of 12 mm it can be calculated that the distance from the centre of rotation of the globe to the apex of the cornea is 1.43 mm greater than the radius of curvature of the sclera.

Park and Park (1933) found the centre of rotation of the globe to be about 13.8 mm posterior to the apex of the cornea, which is similar to the mean value in male emmetropic eyes in our series. This adds support to the suggestion that the apex of the cornea does not lie on the circumference of the globe but protrudes beyond it.

The correlation between the axial length, as measured by the present method, and the refraction is similar to that obtained by Stenström (1948) by ultrasonography, and suggests that even if we are not measuring the true axial length of the eye the dimension measured is so closely related to the axial length that it is valid for clinical purposes. The slope of the regression line for axial length/refraction is such that a change of refraction of 1.00 D is equivalent to a 0.39 mm change in axial length.

Some idea of the consistency of the readings may be obtained by comparing the paired readings of corneal radius and axial length made on each eye. The two measurements of corneal radius were identical in 52 of the 80 eyes, and differed by 0.05
mm in 13 and 0.10 mm in 12 eyes. As would be expected, the differences between the paired readings of axial length were greater; the measurements were identical in 13 eyes but differed by over 1 mm in eight eyes. Four of these eyes were highly myopic with poor fixation and two were highly hypermetropic, also with poor fixation. The mean difference between paired readings for 80 eyes was 0.43 mm.

In spite of the theoretical objections to this photographic method the excellent correlation between the measurements and refraction suggests that the method is a useful alternative to ultrasonography. In addition it is quick to do, comfortable for the patient, and does not demand expensive apparatus.

**Summary**

By photographing the corneal reflex in two positions of gaze and measuring the radius of curvature of the cornea it is possible to calculate the radius of rotation of the eye. The measurements obtained in this way showed a high correlation with refraction in a series of 80 eyes. The axial length obtained by this method was about 3 mm greater than that obtained by ultrasonographic or x-ray methods, and the reasons for the discrepancy are discussed.

**References**


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SORSBY, A., and O'CONNOR, A. D. (1945) *Nature (Lond.*), 156, 779