Corneal and scleral distensibility ratio on enucleated human eyes*

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The rigidity of the cornea and sclera was measured on ten enucleated human eyes by means of the distensibility ratio test. The eyes were obtained from the Medical Eye Bank of Maryland with the donor age ranging from 63 to 86 years. The time of anterior-posterior and equatorial measurements varied from 2 to 32 hours after enucleation. Changes in distensibility were recorded with a circumference gauge when pressure was elevated over a 100 mm Hg pressure span. Scleral distensibility was greatest when a pressure change from 20 to 30 mm Hg was recorded and decreased exponentially until approximately the 90 mm Hg pressure level. Depending on the time elapsed after enucleation, the data on corneal distensibility was a curve of an S-shape pattern with maximum and minimum values. Maximum was recorded near the 50 mm Hg level on a freshly enucleated eye. The maximum value increased and shifted toward lower pressure levels as time between enucleation and measurement was prolonged. In a test taken 32 hours after enucleation the maximum value was recorded at the initial pressure change from 20 to 30 mm Hg. At this time interval the S-shape pattern of the curve was absent and the distensibility decreased uniformly as pressure was elevated. A statistical evaluation for the scleral part of these eyes showed no significant deviation. The characteristic of the corneal distensibility curve, however, showed clearly that the corneal distensibility was a function of two variables, namely age of donor and time elapsed after enucleation.

**Keys words:** distensibility, ratio, donor, cornea, sclera, gauge, rigidity.

The purpose of this study is the examination of separate dimension changes of the cornea and sclera on enucleated human eyes, measuring the distensibility of these tissues by the distensibility ratio test. When ocular rigidity is measured by means of tonometry, it is a combined approximation of two distinct tissues, cornea and sclera. During rising intraocular pressure it is difficult to measure the behavior of these tissues separately when tonometric and manometric methods are used. Corneal and scleral tissue behavior was emphasized in this investigation by performing measurements at intervals up to 32 hours past enucleation. By direct transmission of outer-coat changes to the recording device, the distensibility ratio test

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enabled us to make the following observations.

1. Scleral rigidity changes on a group of eyes from donors between 63 to 86 years of age showed no significant deviation.

2. Corneal distensibility changes exceeded those of scleral distensibility changes with increasing time after enucleation.

3. Eyes examined shortly after enucleation showed the greatest increase in corneal distensibility at 40 to 50 mm Hg.

Materials and methods

Ten enucleated human eyes were obtained from the Medical Eye Bank of Maryland with the donor age ranging from 63-86 years. In addition, an eye from a 3-day-old infant was included in this study. The time of measurement varied from 2 to 32 hours after enucleation. The method of measurement was the same as the one previously reported using rabbit eyes.1

The eye being measured was prepared in the following way. The eye was first brought to room temperature after which the pressure of the eye was raised to 20 mm Hg. Pressure was inducted by cannulation of the anterior chamber to a saline reservoir. A circumference gauge which was used to measure direct outer-coat changes of the eye was placed around the anterior-posterior plane with an initial stretch of 0.8 mm. Assuring no slippage of the gauge the eye was placed in a moist container and kept at room temperature. The pressure was raised in 10 mm Hg increments and a 5 minute interval preceded each step to allow sufficient time for the eye to reach a new steady state. After the maximum elevation of 120 mm Hg was reached, the valve to the reservoir was turned off and the reservoir was lowered to the original 20 mm Hg level. The valve to the reservoir was turned on again after approximately 25 minutes which was the time required for the eye to return from the 120 mm Hg to 20 mm Hg level. This procedure was repeated two times after which the circumference gauge was removed from the anterior-posterior plane and applied around the equator. The initial stretch of the gauge had to be of the same magnitude for both anterior-posterior and equatorial measurements to attain meaningful results. Equatorial recordings were carried out identical to those of anterior-posterior recordings.

There existed a linear relationship between the pressure, electrical resistance, and length of the gauge, which allowed direct substitution of the obtained data into the introduced equations used in the rabbit experiment.1 The data was the average of three runs taken for either anterior-posterior or equatorial measurements. From this average, the distensibility was computed using the above equations in incremental form. The computed distensibility was fitted into the curves of Figs. 2, 3, 4, and 5. Irregularities were noticed in the measurements near the 70 mm Hg level. For this reason we have drawn the line through the beginning and end points and have chosen a point in between where irregularities occurred.

It was also shown in the rabbit experiment,1 that a relationship exists between the introduced form of measurement Ds and the pressure-volume measurements of Dv. A transformation was made from the calculated distensibility Ds for the approximation of volume changes shown in Fig. 6.

Results

The measurements in this experiment included three known variables; time elapsed after enucleation, the time intervals after death, and the age of the donor. The results showed that these variables had little effect on scleral distensibility. When statistically analyzed there existed little deviation among the eyes in this age group (Fig. 1).

These variables, on the other hand, have influenced the distensibility of the cornea. In Fig. 2, eye H-2, the corneal-scleral distensibility ratio of an eye was measured immediately after enucleation. The eye was enucleated as part of an extenteration for a malignant orbital tumor in a man aged 63, and was a normal eye. The scleral distensibility recorded a maximum when a pressure change from 20 to 30 mm Hg was made and decreased exponentially to a steady state near the 90 mm Hg level. The corneal distensibility which was calculated for each incremental pressure change of 10 mm Hg elevation showed an S-shape pattern with decreasing values up to the 40 mm Hg level. This was followed by an upward swing with a peak near the 50 mm Hg level. From there the values decreased to a steady state near the 90 mm Hg level. The second part of Fig. 2, N-1, was an eye which was tested 16 hours after enucleation. The characteristic of the scleral distensibility curve was
Fig. 1. Distensibility values of the sclera measured from 10 enucleated normal human eyes, ages 63 to 86, including ± standard error.

Fig. 2. Relationship of corneal and scleral distensibility. (A) Normal human eye H-2, measured immediately after enucleation. (B) Normal human eye N-1 measured 16 hours after enucleation. The ratio measurement was taken at 10 mm Hg increments and the calculated $\frac{\Delta L}{\Delta P}$ value for each particular level was plotted against pressure.
Fig. 3. Relationship of corneal and scleral distensibility. (A) Normal human eye N-4, measured 24 hours after enucleation. (B) Normal human eye N-10, measured 28 hours after enucleation.

identical to that of the first part of Fig. 2. The distensibility curve of the cornea was similar to the first part with greater maximum values at the 50 mm. Hg level. In Fig. 3 the distensibility was tested on eyes 24 and 28 hours after enucleation. Little change was observed in scleral distensibility from the eyes of Fig. 2. The corneal distensibility curve was different in that it did not produce the negative part with minimum values at the 40 mm. Hg level. Instead the curve went positive with greater maximum values. It was also observed that the positive part of the curve shifted toward the left. In Fig. 4, measurements were taken on the same eye at intervals of 6 and 32 hours after enucleation. The 32 hour test was the longest duration in the series tested. The results of the six hour test were similar to those of the eyes tested 2 and 16 hours after enucleation. The 32 hour test however, produced no S-shape pattern for the corneal distensibility curve. The maximum value shifted all the way to the left, meaning that maximum distension took place at a pressure change from 20 to 30 mm Hg. The scleral distensibility was nearly the same for the 16 and 32 hour time interval.

We also were able to test an eye from a 3-day-old infant donor. The results on corneal distensibility from the infant eye differed from the eyes of an older donor. The measurements of corneal and scleral distensibility for this eye (Fig. 5) showed that both values decreased nearly parallel to a steady state near the 90 mm. Hg level.

The distensibility ratio test on two eyes in the series (not illustrated) showed considerable increase of distension for the cornea at the 40 to 50 mm. Hg level of an 86-year-old eye when compared with the 71-year-old eye; both were tested at the same time intervals after enucleation.

The increase of distensibility at the indicated critical pressure levels of 40 and 50 mm. Hg was considered to be a balloon effect of the cornea. This balloon effect
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Fig. 4. Relationship of corneal and scleral distensibility of a normal human eye N-11, measured at 6 and 32 hour intervals.

was greater when the time elapse after enucleation was longer before measurements were made, and occurred at lower pressure levels. The magnitude of this balloon effect as observed was attributed to both variables, the age of the eye and the time elapse after enucleation; while the shift of the curve to the left was attributed to time elapse after enucleation only.

In the three-day-old infant eye there was no balloon effect noticeable in the cornea, which suggests that the sclera and cornea are very similar in anatomic makeup, and the two tissues become progressively more different with age. The curve of Fig. 5 compared very closely to the curves obtained from 10-week-old rabbits.1

The decay time or the time when the initial pressure was reached after the elevation of pressure to 120 mm. Hg was approximately 25 minutes. At high pressures decay occurred more rapidly than at pressures near the normal intraocular pressure level. In this experiment all eyes returned from the 120 mm. Hg level in 25 minutes. A time of 45 minutes was required to return from 23 to 15 mm. Hg. The pressure of the eye was usually reset to 20 mm. Hg once it reached 23 mm. Hg. Lyon, McEwen, and Shepherd5 reported similar decay time intervals.

The presentation of the data on corneal and scleral distensibility was plotted in an exponential decreasing pattern. The distensibility for each particular pressure level was calculated and this particular value was plotted against pressure. For comparative studies the data of Fig. 2, H-2, N-1; Fig. 3, N-10 was plotted using volume-pressure and pressure coordinates (Fig. 6).

Discussion

The measurements, which were made by the circumference gauge, are of the same category as those of any commercially available strain gauge (transducer), with one exception, that corneal and scleral dimension changes can be differentiated by the circumference gauge method. The validity of this method was tested using rabbit eyes.1 The data on scleral changes in this investigation are of similar nature as reported by other investigators concerning measurements of the whole eye.3-6 The detected corneal changes, on the other hand, are different and not similar to the scleral changes.

The results indicate that the difference of scleral distensibility between 30 and 80-year-old donor eyes is small. Corneal distensibility differences between the eyes of this age group appear to be more significant as seen in a 71 and 86-year-old eye donor; measured at identical time intervals after enucleation. Significant changes are noticeable on corneal distensibility measurements when the time between measurement and enucleation is prolonged. These differences are not observed in scleral distensibility measurements, even when the time difference of measurement and enucleation is extended to the 32 hour interval. The data on corneal distensibility
Fig. 5. Relationship of corneal and scleral distensibility of a 3-day-old infant measured 18 hours after enucleation.

Fig. 6. Relationship of corneal and scleral distensibility from data of Fig. 2, H-2, N-1; and Fig. 3, N-10, expressed in volume-pressure coordinates. The upper scale is expanded for corneal values in microliters per millimeter of Hg. The lower scale accommodates scleral values in microliters per millimeter of Hg. Identification of curves are as follows: • H-2 cornea, ○ N-1 cornea, x N-10 cornea, ▲ H-2, N-1, N-10 sclera.
showed the same S-shape pattern on all eyes tested between the age of 63 and 86 with greatest distension recorded between the 30 to 50 mm. Hg level, depending on the time of measurement. If the distensibility of the cornea is measured 6 hours after enucleation, greatest distension is recorded near the 50 mm. Hg level. If the measurement took place 24 hours after enucleation, greatest distension is recorded near the 30 mm. Hg level. The amount of distension also increased with time after enucleation and with increasing age. This significant change we call the balloon effect. It appears that the tissue acts at these pressure levels in a balloon-like fashion, bulging out progressively as pressure increases.

The corneal distensibility measured on an infant eye in this series is similar to that of 10-week-old rabbit eyes tested in our laboratory. In the rabbit experiment the distensibility was measured immediately after enucleation and the results showed that corneal and scleral distensibility decreased nearly parallel in an exponential pattern, with one cross-over point at 90 mm. Hg. At this level the value of corneal distensibility became larger with respect to that of scleral distensibility. A similar pattern is observed when the data of the infant eye is plotted. The S-shape curve as recorded on older human eyes is absent. These similarities of both species, infant and rabbit eyes, may be explained by a morphologic basis, but our experiment does not suggest any specific mechanism.

Our experiments show a greater corneal distensibility in older aged donor eyes which could be a significant factor in corneal transplantation. This greater distensibility may reflect the general state of the cornea and indicate changes from age have occurred in the stroma. The greatest distensibility at lower pressures with increasing time after enucleation may also indicate a deterioration in the corneal stroma, perhaps from early autolysis. The greatest change in our series occurred between 24 and 32 hours, but there was a progressive change between 2 and 24 hours after enucleation.

The marked increase in distensibility seen between 40 and 50 mm. Hg may explain the corneal edema seen clinically in patients with rapid increases in intraocular pressures to these levels. The cornea may distend so that the endothelium can no longer stretch to cover the entire posterior surface, resulting in separation between the cells with resultant edema.

REFERENCES