Volume change of the ocular lens during accommodation

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The eye is able to form a clear image on the retina from objects situated within a wide range of distances due to a process called accommodation. In higher vertebrates, including humans, accommodation results from changes in crystalline lens shape and surface radii of curvature (13).

When the ciliary muscle is relaxed and flattened against the sclera, the zonulae adjoining the ciliary body and the lens capsule are under tension and thus pulling eccentrically on the lens equator. This action causes the lens to adopt a relatively flattened shape with a larger equatorial diameter and a shorter A-P length, which allows focusing on virtual infinity (zero accommodation). When an individual focuses on a near object, the ciliary muscle contracts (shortening its distance to the lens equator), the zonulae relax, and the lens as a whole adopts a relatively rounded shape, which is its normal tendency. Physically, these changes in lens shape inevitably must involve changes in either capsular surface area or lens volume, or both.

Classic theories of lenticular accommodation suggest that the volume of the intraocular crystalline lens remains constant during the accommodation process (16, 17, 30). No empirical studies have demonstrated that the volume actually stays constant. Because of the physical principle mentioned above, an assumption for a constant volume implies that the surface area of the lens must change during accommodation.

Furthermore, most of the anterior capsule, where the main changes in curvature occur during accommodation (11, 24), both covers and serves as the basement membrane for the single layer of epithelial cells, which could be disrupted if the capsule surface area changed extensively. Only the epithelial cells in the equatorial region are arranged in a multilayered configuration (18). It is also well known that the capsule and the internal fiber cells are freely permeable to fluid. In vitro experiments have demonstrated that osmotic forces can swell and shrink crystalline lenses (10).

Thus we decided to examine the possibility that it is primarily the lens volume that changes during accommodation with relatively limited associated changes in surface area. For this purpose, we characterized 1) an in vitro model: the isolated iris-ciliary body-zonulae-lens complex dissected from bovines, and 2) a theoretical model: the graphical construction of human lenses from structural parameters acquired from the literature.

The bovine lens was chosen because of the following reasons: its ability to be obtained fresh, its large size that allows for determination of small volume changes, and its abundance at a low cost. We are aware that the bovine lens has limited accommodation amplitude given its internal fibers structure (19). However, it serves our purpose, namely, to show that deformation of a mammalian lens results in volume changes.

Given the complex geometric shape of the lens, an accurate measurement of its volume is not easy to determine with certainty. Hence, we developed a method to compute the volume of the lens from lateral photographs. The approach takes advantage of the topology of the lens as detailed in METHODS. Our results suggest that during the accommodative process, the lens gains or looses ~2–8% of its volume as it gets rounder or flatter, respectively. Our findings also suggest that fluid must move in and out of the lens during this process, possibly aided by the numerous aquaporins connecting the fiber cells (1, 31, 32). With preliminary calculations we determined that this volume flow could occur within the time frame of the rapid accommodation process.
**METHODS**

**Determination of Lens Volume From Lateral (Sagittal) Photographs**

The torus is a topological body similar to a doughnut. Its volume can be calculated from the cross-sectional area (CSA), where \( \text{CSA} = \pi \times r^2 \), and from the diameter of the circle \( d \) that perpendicularly crosses the center of mass (CM) of the CSA (Fig. 1A) such that volume of torus \( \pi \times r^2 \times d \).

The following example could aid in illustrating this concept: the volume of a cylinder is calculated by multiplying the CSA (of the circle) by its height \( h \). The center of the circle is also the CM. If we bend the cylinder so that the base joins its top, we create a doughnut, with the length \( h \) along the CM remaining constant. The volume of the body is also constant, even though the inner ring diameter of the resulting doughnut is relatively compressed and its outer ring diameter expanded (Fig. 1B).

The horn torus is considered the same topological body as the torus, but without the center hole (Fig. 1C). The lens can be compared with a horn torus. When the lens is observed from the side (sagittal view), 90° from the anterior-posterior (A-P) axis that crosses the center, a deformed oval can be seen (Fig. 2); rotating the lens around the A-P axis does not change the image. The total area of this shape is the CSA of the two sides of the horn torus. Therefore, the volume of the lens will be obtained by multiplying the CSA of one of the halves of this area (that is separated by the A-P axis) times \( \pi \) times the length between the CMs of the two symmetrical halves of the lens, which corresponds to the diameter of the circle that rotates around the A-P axis, as volume of lens \( \pi \times r^2 \times d \) (Fig. 2).

\[\begin{align*}
\text{Volume of lens} &= \text{CSA} \times \pi \times d \\
\text{Perimeter} &= \pi \times d \\
\text{CSA} &= \pi \times r^2 
\end{align*}\]

**Figure 2.** Sagittal view of a lens showing its total cross-sectional surface area. This is divided into 2 identical CSAs for the right (CSAR) and left (CSAL) sides. The 2 CMs are indicated. A perpendicular circle going through the CMs (solid and dashed lines) is also shown. A-P thickness, length of anterior-to-posterior axis.

**Dissection, Isolation, and Mounting of the Bovine Ciliary Body-Zonulae-Lens Complex**

Bovine eyes were obtained within 30 min of death, from a local slaughterhouse in Argentina, where experiments were done. Each eye was dissected by making a circular cut around the sclera 10 mm posterior to the limbus. The vitreous was completely removed from the lens. The entire ciliary body was carefully separated from the sclera by microdissection and then scooped out with a Teflon spatula. At this point, the zonulae relaxed and the lens acquired its most rounded shape, not different from a completely isolated one. The stromal side of the iris-ciliary body (ICB) was attached with cyanoacrylate glue to a rubber washer with an external diameter of 45 mm and a central aperture of 20 mm in diameter so that the lens was suspended within the opening of the washer. The washer with the glued ICB-zonulae-lens complex was then placed horizontally on an aluminum platform of a custom-built stretching device. Subsequently, eight small metal hooks arranged symmetrically around the whole circumference were used to clasp the preperforated outer edge of the washer (Fig. 3). The hooks were connected to a rotating flywheel with unstretchable strings. Turning the round dial elongated the washer radially, uniformly augmenting its central opening while maintaining its circularity. This maneuver applied tension to the zonulae, which in turn transmitted the tension to the lens and changed its shape in a manner simulating the unaccommodative state (i.e., maximal reduction in the A-P sagittal thickness). Relaxing the tension simulated the opposite, or accommodative, state (i.e., minimal equatorial length).

Experiments were performed in several conditions: 1) the setup was completely submerged in a bath with Tyrode solution (composition elsewhere, Ref. 7), while the stretching and relaxing maneuvers were performed reversibly; 2) similar to the previous condition, but immersed in corn oil, instead; and 3) combinations of the first two protocols described. The whole arrangement was temporarily exposed to air, as needed, for mechanical measurements and digital photographing in each of the two oppositely imposed accommodative states. The visual axis of the photographic camera was on a perpendicular plane with respect to the A-P axis of the lens, validated by determining that the two CSAs were symmetrically identical and that each CSA was a minimum.

With the use of graphics software (Photoshop), the sagittal outline of the lens was obtained from the digital images, and this outline was further cut exactly in half for subsequent analysis of both photographs as described later. A depiction of such outlines in the stretched (no accommodation) and relaxed (maximum accommodation) positions is shown in Fig. 4.
Volume Determination

Calibration for Conversion of Pixels Into Millimeters and Volume Determination

Before photographs were taken, the equatorial diameter was determined by placing a plastic (acetal copolymer) washer that corresponded to the closest fit around the equator of the bovine lens. The internal diameter of this plastic washer (custom-milled with a precision of 0.1 mm) indicated the equatorial length. Similarly, a vernier caliper was used to determine the A-P thickness (length from anterior to posterior poles through the A-P axis) with resolution of 0.1 mm.

The needed dimensions and surfaces of the whole lens and its symmetrical halves, in both accommodative states, were obtained with ImageJ software (http://rsb.info.nih.gov/ij/) in pixels, and the pixel values were converted to millimeters for volume calculations. An example of such step-by-step analysis follows.

1. From the outline obtained with Photoshop of one complete lens, equator length and A-P thickness were determined. The equator length of this representative lens was 389.4 pixels, and the value obtained from the measurement with the plastic washer was 18.2 mm; therefore, the conversion was 21.39 pixels/mm. The A-P thickness was 276.0 pixels, which upon conversion yielded 12.9 mm, a value that corresponded exactly to that obtained with the vernier caliper for the length of the A-P axis. As for the CSA of the entire lens, the CSA of the half lens was first obtained (43,063.0 squared pixels). The square root of this value converted to millimeters (by dividing by the conversion factor) was squared and multiplied by two to get 188.2 mm².

2. In the photograph of the same lens, but cut exactly in half along the A-P axis, the CSA and the distance from the A-P axis to the equator pole were found to be 21,531.5 and 194.7 pixels, respectively, and were compared with the pixel values obtained for the whole lens divided by 2. These compared values were less than 0.5% of each other (in this case there was no difference), so the half lens picture was kept for further study. If the error was larger than 0.5%, the half lens would be disregarded and a new half lens outline would be cut, until it fell within the error set as standard. The A-P thickness of the whole lens and the halves had to match precisely.

3. In the half lens, the location of the CM, perpendicularly measured from the A-P axis, was 84.43 pixels, or 3.95 mm. This length is the radius \( r \); therefore, \( 2r \) equals 7.90 mm, the value for \( d \). Applying the volume equation, \( 94.1 \text{ mm}^2 \times \pi \times 7.90 \text{ mm} = 2,334.7 \text{ mm}^3 \), or 2.33 ml.

The method was corroborated both by weighing a custom-made acrylic lens (of known density) and by determining its volume with a volume displacement apparatus with a capillary. Furthermore, with a machined plastic lens of known volume, the photographic method described yielded values within 1%.

Calculation of Volumes on the Theoretical Human Lens

Adolescent human eyes can attain up to 14 diopters (D) of accommodation, a property that declines with aging (a diopter measures the power of a lens and is equal to the reciprocal of the focal length of the lens in meters).

Human crystalline lenses of 20 and 45 yr of age were chosen to be depicted in their unaccommodative (0 D) and in their purported maximal accommodative states (10 and 4 D, respectively). The resulting drawings represented a sagittal cut from the A-P side through the A-P axis. The final outlined schematics were drawn in Photoshop. The resulting CSAs from both accommodative states, at both ages, were used to calculate their volumes as was done with the images of the bovine lens.

Most parameters needed for the sketches of the lenses were obtained or calculated from information available in the literature (4, 5, 12, 25, 28). Stepwise description of the construction from the available data is shown below. An assumption in the present study is that lenses change the CSA and the volume with minimal or no CSA perimeter change. Therefore, the perimeters of the constructed lens CSAs were kept constant.

Construction of Human Lenses

Accommodated lenses from in vitro data. Isolated postmortem human lenses presumably manifest their most rounded conformation because they are devoid of any tension from zonulæ and ciliary body.
Therefore, it was assumed that the shape of such lenses corresponds to the largest ocular accommodation for its age. For example, for a 20-yr-old, an overall eye accommodation of 10 D was assumed to be the maximum for that age (4, 15), even though the eye could in principle accommodate slightly more or less at age 20 (15).

Rosen et al. (25), in their research on excised human lenses from cadavers (ages 20 to 99 yr), developed a linear regression analysis of curvatures of the anterior and posterior surfaces, as well as A-P sagittal thickness and equator diameter. Most of the formulas for creating the accommodated lenses were extracted from this study.

As an example, for the creation of the 20-yr-old lens in Photoshop, from an eye that accommodated 10 D, the radius of curvature of the anterior aspect (\(R_a\)) was obtained from Rosen’s formula:
\[
R_a = 0.046 \times \text{age} + 7.5
\]
A circle with
\[
d = 16.9 \text{ mm}
w
\]
was then depicted (Fig. 5). In the aforementioned study it was found that the posterior aspect radius of curvature (\(R_p\)) does not change with age; therefore, the reported \(R_p\) value of 5.5 mm was doubled to draw a circle with
\[
d = 11.0 \text{ mm, which corresponded to the posterior aspect of the accommodated 20-yr-old lens.}
\]
The next step was to find the A-P thickness using the formula A-P thickness = 0.0123\(\times\) age + 3.97. A value of 4.22 mm was obtained.

The two circles were then superimposed with their centers aligned on the same axis, until the maximal distance between the portion of the circle (arc) that represented the anterior aspect was at 4.22 mm of distance from the arc representing the posterior aspect. Subsequently, the equator length was calculated as 0.0138\(\times\)age + 8.7. The value calculated for the equator was 8.98 mm.

Near the equatorial periphery (the bow zone), the curvature radii on the anterior and posterior sides of the equator become smaller. Therefore, as a final step, two smaller circles were sketched to adjoin both surfaces at each end of the equator. The circles with a radius that was 8.28 times smaller than the equator’s radius, called “end caps,” were placed to join tangentially the anterior and posterior at certain angles as proposed and modeled by Burd et al. (5) and Schachar et al. (27). The resulting outline was cropped and analyzed as described above for the bovine lens.

Information from in vivo lenses. For drawing the lenses with 0 D accommodation, linear regression analysis developed by Dubbelman et al. (12) from Scheimpflug images on live subjects were mainly used. Values for \(R_a\), \(R_p\), and A-P thickness, as well as the total diopters of the accommodated lenses (ACM) were needed to calculate the curvatures of the unaccommodated lenses (UCM) as follows:
\[
\text{UCM } R_a = \text{ACM } R_a + (0.62 \text{ mm} \times \text{D of ACM lens}),
\]
\[
\text{UCM } R_p = \text{ACM } R_p + (0.13 \text{ mm} \times \text{D of ACM lens})
\]
and
\[
\text{UCM A-P} = \text{ACM A-P} - [(0.058 - 0.00048 \times \text{age}) \times \text{D of ACM lens}].
\]

After the circles were drawn with the calculated curvatures, they were symmetrically approached in a fashion similar to the maximally accommodated lenses from the in vitro data to the specified A-P thickness. Since there are no reliable studies on equator lengths of unaccommodated in vivo lenses, the equator and the end caps were fitted into the shape via trial-and-error method, until the equator and the end caps joined the edges of the outlined anterior and posterior lines, respecting the previously mentioned ratio of 8.28 = radius of equator/radius of end cap.

All of the human lenses diagramed (Fig. 6) were analyzed in a manner similar to that described earlier for the bovine lenses by using ImageJ to obtain the measurements needed and by applying the modified horn torus formula to calculate the volumes.

RESULTS

The Bovine Lens

Tables 1 and 2 list the data obtained with the bovine lens. Of the three parameters presented, A-P length and equator diameters were actual mechanical measurements, included to demonstrate differences during relaxing (set as “control” for our purposes) and stretching of the lens, akin to accommodative changes within the in vivo eye, and were used in the calibration process to convert pixels to millimeters. Both factors are discussed later for their implication in dioptric power changes as a result of their different curvatures and thicknesses. The third parameter, the volume, was a value calculated from the analysis of the digital pictures.

Change in shape and volume of the lens submerged in Tyrode solution. Two sets of experiments were performed in which the whole experimental setup was submerged in
Tyrode solution (Table 1). In set 1 (n = 7), the naturally relaxed lens (with no imposed tension) had an A-P length of 12.5 mm, and a 3.2% reduction was achieved when the lens was stretched (unaccommodated). On the same maneuver, the equator increased 2.2% from 18.0 mm to 18.4 mm. Analyzed were stretched (unaccommodated). On the same maneuver, the equator increased 2.2% from 18.0 to 18.4 mm. Analyzed was stretched under oil; however, there was a marginally significant recovery of the control values when lenses were relaxed while still under oil, probably due to the natural shape of the lens somehow being distorted in the oil maneuvers. Nonetheless, there was a clear restoration of both parameters when lenses were returned to control conditions in Tyrode solution.

The Human Lens

The results shown in Table 3 demonstrate that in a 20-yr-old lens changing from the fully accommodated state (10 D) to the unaccommodated state (0 D), the A-P thickness decreases 13.1%, equator diameter increases 2.9%, and CSA decreases 7.1%, and these changes result in a 2.6% decrease of the volume from 0.155 to 0.151 ml.

The lens parameters that were obtained from the sketches of the 45-yr-old lens at 4 and 0 D are, respectively, as follows: A-P thickness of 4.52 and 4.38 mm (3.2% reduction), equator diameter of 9.32 and 9.41 mm (1% augmentation), CSA of 15.45 and 15.14 mm² (2% decrease), and finally, a volume decrease of 1.7%, from 0.183 to 0.180 ml.

**DISCUSSION**

Our results confirm in two different mammalian models, the in vitro bovine crystalline lens and the modeled human lens, the hypothesis that lenses gain and lose volume during accommodation and unaccommodation, respectively. In the bovine, a reversible 6–8% change was observed, and in the human, a 2–3% increase of volume was calculated with increased accommodation.

The bovine accommodative amplitude has not been studied previously but is estimated to be low, less than in primates and more than in rodents, perhaps no more than 2 D (3, 23). To approximate the modification in dioptric power that the changes in volume in our experiments represent, the bovine lens gain and lose volume during accommodation and unaccommodation, respectively. In the bovine, a reversible 6–8% change was observed, and in the human, a 2–3% increase of volume was calculated with increased accommodation.

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tive indexes for the lens, aqueous, and vitreous humor (21, 22), the equivalent dioptric power of the bovine lens was computed using the Gullstrand’s equation for thick lenses. From 11 bovine lenses, a mean value of $14.8 \pm 0.25$ D was calculated for the unaccommodated (stretched) lens, whereas the value for the accommodated (relaxed) lens was $16.3 \pm 0.23$ D. These values probably represent only a fraction of the total equivalent power for the whole simplified eye. However, with other factors being constant, the change was statistically significant ($P < 0.01$ as paired data), representing the lens contribution to accommodation, although we clearly cannot say with certainty what the real dioptric powers of the lens within the in vivo eye actually are. The fact that with a change of 1.5 D in lens equivalent power there was an 8% change of volume means that the magnitude of the changes of accommodation and volume in vivo could be even higher if the range of accommodation were larger. We did not measure the force that we applied to deform the lens simulating the natural accommodation.

Nevertheless, the process was reversible and the anatomical structures remained intact, indicating that they could withstand an equivalent or even larger force in vivo. Even if the bovine eye does not accommodate, it serves as a model to show that lens deformation is associated with volume change. In the

![Diagram of lens deformation](http://ajpcell.physiology.org/)

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**Table 2. Changes in bovine lens dimensions and volume upon simulated accommodative changes in oil submersion**

<table>
<thead>
<tr>
<th></th>
<th>Relaxed</th>
<th>Stretched in Oil</th>
<th>Relaxed in Tyrode</th>
<th>Stretched in Tyrode</th>
</tr>
</thead>
<tbody>
<tr>
<td>A-P Length, mm</td>
<td>12.1</td>
<td>12.3</td>
<td>12.1</td>
<td>12.3</td>
</tr>
<tr>
<td>Equator Diameter, mm</td>
<td>11.8</td>
<td>12.0</td>
<td>11.8</td>
<td>12.0</td>
</tr>
<tr>
<td>Volume, ml</td>
<td>1.74</td>
<td>1.77</td>
<td>1.75</td>
<td>1.77</td>
</tr>
</tbody>
</table>

Mean of last 4 experiments: A-P Length, mm = 12.3, Equator Diameter, mm = 11.9, Volume, ml = 1.77

%Change:

- A-P Length: $-3.3\%$
- Equator Diameter: $+2.3\%$
- Volume: $+1.7\%$

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**Table 3. Dimensions and volumes of 20- and 45-yr-old human lenses during extremes in accommodative states**

<table>
<thead>
<tr>
<th></th>
<th>20-yr-old lens</th>
<th>45-yr-old lens</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACM (10 D)</td>
<td>4.22</td>
<td>4.52</td>
</tr>
<tr>
<td>UCM (0 D)</td>
<td>3.73</td>
<td>4.38</td>
</tr>
<tr>
<td>%Change</td>
<td>$-13.1$</td>
<td>$-3.2$</td>
</tr>
</tbody>
</table>

CSA, cross-sectional area; ACM, accommodated (relaxed) lenses; UCM, unaccommodated (stretched) lenses; D, diopter, a measure of the power of a lens.
experiments performed under oil, stretching also produced a decrease in volume. The lost fluid was dispersed in the oil, and upon release of the stretching forces, the lens did not regain its volume and its shape was distorted. Obviously, when the lens is perturbed from its natural relaxed, rounded state by stretching, internal forces develop that are probably only dissipated by fluid absorption. This springlike behavior of the lens fibers has been described by Kuszak et al. (19). They compared the tension developed inside the lens fibers to a springlike phenomenon that tends to return the lens to its lower energy natural accommodated state. They also pointed out that aquaporins (AQPs) and gap junctions predominantly connect the fibers to each other in their central parts, leaving the end of the fibers, which form the lens sutures, free for a limited displacement when the lens changes shape during the accommodation process. They noted as well that the cortex participates in the accommodation process. Although the fibers’ structure of the bovine lens may not allow a wide range of accommodation, findings by Kuszak et al. can be applied to the internal changes that occur in our model.

When an aqueous medium is not bathing the surface of the lens, the lens cannot regain its natural volume and shape, and its sagittal image deforms. When the lens is transferred to Tyrode solution, the lens spontaneously recovers its volume and shape. We could not determine whether the fluid interchange occurs at the anterior or posterior surface, or both, or what were the relative contributions of the lens compartments. Knowing that most of the change in curvature occurs at the anterior face, which is bathed by the aqueous humor, we expect this to be the side of most of the interchange.

An extensive network of water channels (AQP0) communicates the internal lens fibers to each other (31, 32). Furthermore, Mathias et al. (20) proposed a model for an internal circulating system within the avascular lens that results in fluid movement internally within the organ. Fluid is thought to enter the lens at the poles and leave at the equator, facilitated by the syncytial nature of the lens with its extensive internal communication via gap junctions and AQPs. We demonstrated a current distribution in the rabbit lens consistent with the current flows that support the fluid movement in the model by Mathias et al., as well as evidence for an internal fluid movement within the bovine lens (6, 9). Although the natural fluid flow is slow and driven by osmotic forces, the same channels may allow rapid fluid flow during accommodation driven by the external mechanical force. Thus any external force that deforms the lens will force water movement within the lens, as will happen when a sponge full of water is squeezed. The fluid that comes to the outside represents the contribution of multiple compartments that get realigned, with the cortex fibers possibly contributing the most. Eventually, the fluid has to flow across the epithelium and the capsule. The capsule (as a collagen matrix) is highly permeable to water, and the epithelium contains AQPs (26).

Although the lens can swell or shrink under the influence of osmotic forces, there are no studies showing that a few microliters can be expelled across the anterior face in less than a second (2), which is the time required in accommodation. We do not know the force developed inside the lens when stretched, but it should be sufficient to move fluid at the rate required. For technical reasons related to the design of our “stretching apparatus” (rotating the wheel), it took several seconds to stretch the lens, but we felt no particular resistance. Thus we believe that with a more advanced technology, the same volume change can be attained in less than a second. Although we have clearly demonstrated a change in volume of the lens, our model and interpretation also require changes in its surface area (see Fig. 7). We assume that the lens capsule may not stretch radially in the pole-to-equator direction. As the lens is pulled by the zonulae, the A-P distance decreases and the region closest to the equator opens up the most, like a Spanish abanico (ladies fan). This is not different from trying to flatten an upside-down cup. One needs to make radial cuts and fill in the triangular areas between cuts with additional surface. Little change in area occurs at the poles.

In humans, equivalent dioptric powers of 60 D for the eye with the unaccommodated lens and 71 D for the eye with the accommodated lens are typical values for about 10 D of in vivo accommodation. The unaccommodated crystalline lens equivalent power is 22 D; in an eye with 10 D of accommodation, the lens equivalent power is 35 D. Therefore, a change of 10 D change for the whole eye represents a change of 13 D in the equivalent powers of the lens (22).

To validate whether our modeled human lenses (Table 1) were close to the in vivo values, we also calculated the equivalent powers. In the case of the 20-yr-old lens, the 2.6% decrease in volume represented a change of lens equivalent power from 27.1 to 20.6 D. For the 45-yr-old lens, the 1.7% decrease in volume correlated with an equivalent lens power change from 26.3 to 22.6 D.

Furthermore, using magnetic resonance imaging of the human eye in vivo at 0.1 and 8 D, Strenk et al. (30) found that the lens CSA increased with accommodation. They realized that the changes in lens CSA that they observed during accommodation reflected changes in lens volume and suggested that the lens material must be slightly compressed when the lens is stretched (i.e., unaccommodated). Moreover, they also emphasized that their results challenge a long-held belief that the lens is incompressible, based on the fact that it contains a large amount of water, which is incompressible. However, Strenk et al. did not consider the possibility that fluid could leave the lens when it is compressed, as our results indicate. Nevertheless, both our data and those of Strenk et al. are in accord on the point that the CSA increases with accommodation.

Presbyopia, a condition that affects humans as they age, is characterized as a decline in accommodation. Most believe that the presbyopic changes are mainly due to the growth of the lens throughout life and an associated increase in capsular and lenticular stiffness. Several theories have been advanced to explain this change (2, 14, 15, 29). We suggest, in addition, that defective and less permeable AQPs within the lens may inhibit the movement of fluid between the fibers that would be necessary for a rapid deformation of the lens.

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GRANTS

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