A NEW THEORY OF HUMAN ACCOMMODATION: CILIO-ZONULAR COMPRESSION OF THE LENS EQUATOR*

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A NEW MECHANISM OF HUMAN ACCOMMODATION, PREVIOUSLY UNDESCRIBED, is proposed. Hermann Ludwig von Helmholtz,[1] who described the most widely accepted theory, said in 1866, "There is no other subject in physiological optics about which so many antagonistic opinions have been entertained as concerning the accommodation of the eye." Unfortunately, the known theories on the mechanism of accommodation do not satisfactorily explain all observations.

The theory proposed here is based on comparative vertebrate anatomy, re-evaluation of previous studies, evaluation of zonular forces, clinical observations, and a mechanical model of human accommodation. Because it describes the anatomic actions involved, this mechanism is called the "cilio-zonular compression" theory. Unlike existing theories, this theory presumes that the zonular fibers can do more than simply suspend or exert a pulling force on the lens. Indeed, the very basis is that the zonular fibers, driven by the contractual power of the ciliary body, actually transmit the force toward the lens equator, which, being compressed, increases the lens anterior-posterior diameter and makes the anterior and posterior lens surfaces more convex. In physiologic effect, the lens is pushed or squeezed by the forces transmitted through the zonular fibers.

ACTIONS AND THEORIES OF ACCOMMODATION

In 1801, Young[2] proved that it was the lens which changed to make near images focus on the retina. Although many theories on the mechanism of accommodation have been proposed to account for the lens changes, no one theory explains all observations. There are, however, at least six actions that

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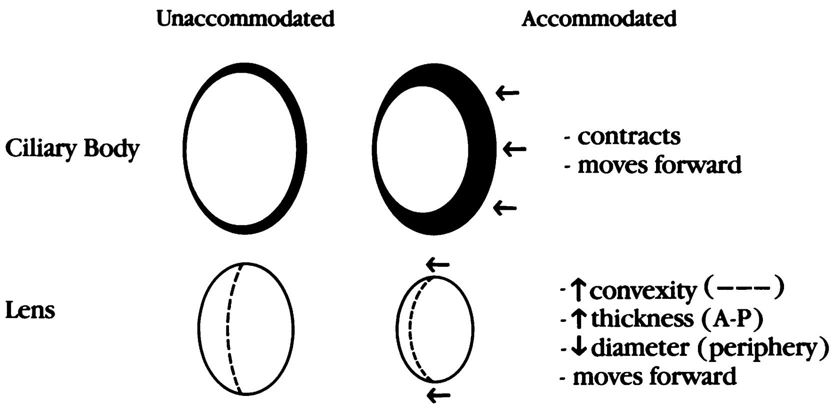

FIGURE 1
Undisputed actions occurring during accommodation. See explanation in text.

seem undisputed: (1) the ciliary body contracts (2) and moves forward while (3) the lens becomes more convex, (4) increases its anteroposterior diameter, (5) reduces its equatorial diameter, and (6) moves slightly forward (Fig 1).

There are three major theories on the accommodative mechanism, commonly known as zonular relaxation, zonular traction, and hydraulic (Fig 2).

The most widely accepted theory is that of von Helmholtz[1] known as the theory of zonular relaxation or capsular elasticity. He postulated in the mid-1800s that in the nonaccommodated state the lens is flattened by the pull of the zonular fibers, which, in accommodation, become relaxed as the ciliary body contracts, allowing the elasticity of the lens to increase the anteroposterior diameter and increase the convexity of the two surfaces. Since the Helmholtz theory embodies a passive mechanism, other investigators have sought to explain accommodation as an active process consistent with other bodily processes.

The theory of zonular traction described by Tscherning[3] implies that during accommodation, the zonular fibers pull the lens so that the anterior and posterior capsules flatten in the periphery, which, along with vitreous pressure, causes the lens capsule to bulge. Some investigators have termed this peripheral flattening as "compression" of the equator secondary to zonular fiber tension, which is opposite of the direct compression used by this author. Several theories generally labeled hydraulic[4-6] postulate that the aqueous or vitreous, either with or without zonular fiber action, exerts pressure on the lens after the ciliary body contracts, with resultant changes in the lens.

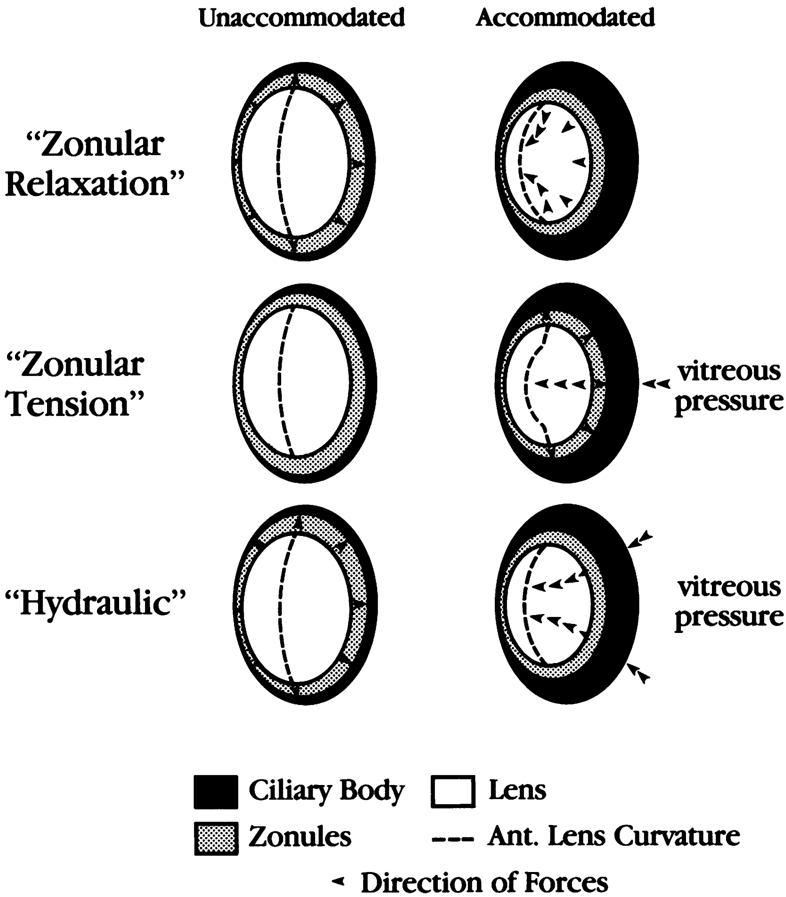

FIGURE 2
Three major theories of accommodation. Note direction of zonular fiber forces.

Although the Helmholtz theory is the most accepted, it cannot explain the following: (1) rapid reproducibility, (2) reduction of accommodation with age, (3) the forward movement of the lens in accommodation, (4) the relation of accommodation to myopia, glaucoma, and strabismus, (5) potentiation of accommodation by convergence, and (6) the ability to overcome accommodative fatigue, even if only momentarily.

COMPARATIVE VERTEBRATE ANATOMY

One of the mysteries of comparative anatomy is that accommodation in the human is not as well developed as that in phylogenetically lesser forms. When we review the action of the Sauropsida (reptiles, except snakes, and birds), we find that accommodation is an active process, where the ciliary body "squeezes" the edge of the lens through the annular pad.[7] Fig 3 compares the human and Sauropsida anatomy.

A mechanism similar to that of the Sauropsida would explain many of the inequities in our human system of accommodation.

REVIEW OF THE SCIENTIFIC LITERATURE

Numerous examples in the reported literature endorse the author's theory of zonular compression.

Descartes,[8] in 1677, without knowledge of fine anatomy, postulated an action similar to that of the Sauropsida, where the ciliary body changes the shape of the lens.

Mueller, in the early 1800s, suggested that the ciliary processes might touch the lens equator to change its shape, but his theory was discounted because there was no physical evidence that the ciliary processes touched the edge of the lens.[1]

Graves,[9] in 1926, reported his now-famous case of trauma, where an anterior and posterior capsule were left without remaining lens substance. Graves' case has been considered a support of the Helmholtz theory. However, on close examination, one cannot explain the 20% increase in the capsule during accommodation (eserine) by elasticity alone. This change can only be accounted for by an additional force that pushes the capsules into the pupillary space.

Luedde,[10] in 1932, in his attempt to support a vitreous theory similar to that ot Tscherning, discussed the work of F. Fischer published in 1907. He shows the histology of two eyes from the same monkey: one eye treated with atropine (nonaccommodated) and the other with physostigmine (accommodated). Clearly, these pictures show the dramatic reduction (by approximately one third) in the space between the ciliary body and lens equator when comparing the atropine-treated eye with the physostigmine-treated eye. The effect of direct zonular compression on the lens equator seems clearly demonstrated here.

Fincham's excellent photographs in a case of aniridia reported in 1937[11] showed that in the accommodated phase, the edge of the lens is irregularly shaped, consistent with an active force on the lens edge.

Busacca's painstaking and excellent drawings (1955) of the zonular fibers

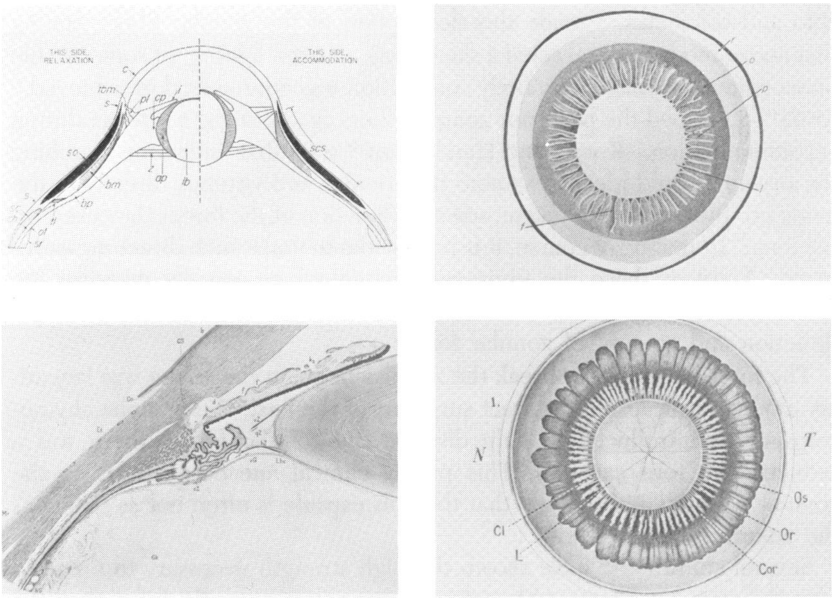

FIGURE 3
Comparative vertebrate anatomy. A: Sauropsida (accommodation in cross-section) (from Walls[7]). CP, ciliary process; AP, annular pad. B: Sauropsida (ciliary processes in accommodation) (from Walls[7]). C: Human anatomy (ciliary processes, zonules, and lens). D: Human ciliary processes and zonules. (Parts C and D reproduced from Salzmann J: *The Human Eyeball.* 1912.)

and ciliary processes as seen through an iridectomy in accommodation[12] show compression of the zonular fibers and the spaces between the ciliary processes and lens. Even his schematic diagram depicts the zonular fibers as shorter in the accommodated state compared with the nonaccommodated state.

Burian and Allen,[13] in 1955, studied changes in the zonular fibers, lens, and angle, which showed that the zonular fibers seemed to angle forward during accommodation and that the vitreous base may or may not bulge forward. Their observations tend to discount the vitreous pressure theories.

ZONULAR FIBER FORCES

To my knowledge, all previous theories on the mechanism of accommodation assume that the zonular fibers can only pull or hold the lens, hence the name "suspensory ligaments." Observations of the zonular fibers by all observers have considered them in a "relaxed" state during accommodation.

Bito and associates,[14] made this description of the zonular fibers, stating that accommodation "revealed a slackening, or even folding, of some zonule fibers when maximal ciliary body contraction was approached or achieved." Araki[15] described the posterior zonular fibers as appearing to "tense during accommodatuion." Koretz and Handelman[16] state that "someone searching for answers would ideally examine the zonules and vitreous directly in the living eye measuring the magnitude and direction of the forces they exert on the lens." In reality, of course, it is impossible to make such direct measurements. Until we have the improved technology to actually measure the forces involved in accommodation, we must infer from indirect studies the direction and amount of zonular forces.

The force necessary to break the zonular fibers in the young was legendary among intracapsular cataract surgeons of the past. When alpha chymotropsin was introduced to help dissolve the zonular fibers, there was a reduction in torn capsules. This purely clinical anecdote attests to the zonular strength and the fact that the lens capsule is often not as strong as the zonular fibers.

Several studies[17-19] have shown the high strength necessary to break or tear the zonular fibers. Although one cannot necessarily infer that the breaking strength is equivalent to the pushing force, there certainly must be a definite correlation.

When one considers the virtually thousands of zonular fiber bundles that attach to the lens equator, it is not difficult to imagine that if the forces were directed toward the lens, a circumferential pressure could be produced, especially in a fluid medium.

MATHEMATICAL CALCULATIONS

In an attempt to determine whether compression of the lens equator through zonular fiber transmission of ciliary body contraction would be physically possible, certain calculations were necessary (Tables I and II).

Taking normal anatomic measurements of a 9-mm lens with a volume of 0.2 ml, the unaccommodated circumlental space (Hannover) volume (limited to that occupied by the zonular fibers) was calculated as 0.23 ml and the accommodated as 0.18 ml.

From histologic preparations along the lens circumference, the number of zonular fibers was estimated at 535,000. This calculation was derived by counting zonular fiber attachments (75/4-μ histologic sections).[20] If there are 250 sections/mm, a 9-mm diameter lens (circumference of 28 mm) will have 535,000 zonular fiber attachments. Zonular fiber bundle diameters have been measured up to 40 μ.

TABLE I: MATHEMATICAL CALCULATIONS IN 9-MM LENS

ANATOMY	MEASUREMENT	NONACCOMMODATED	ACCOMMODATED
Ciliary body	Diameter (inside)	15 ml	13.5-14.0 mm
Ciliary body	Circumference (inside)	47.1 mm	40.1 mm
Circumlental space	Outside lens to inside ciliary body	3 mm	1.5-2.0 mm
Circumlental volume (zonular)	Outside lens to inside	0.23 ml	0.18 ml

TABLE II: MATHEMATICAL CALCULATIONS OF ZONULAR FIBERS IN 9-MM LENS

ANATOMY	MEASUREMENT	NONACCOMMODATED	ACCOMMODATED
Zonules	Number	500,000 (± 125,000)	500,000
Zonules	Insertion on lens circumference	2.5 mm	2.5 mm
Zonules	Diameter	10 μ (4-40 μ)	10 μ (4-40 μ)
Zonules	Mass (10 μ × 3000 μ × 500,000)	0.11 mg	0.11 mg

The zonular fiber mass occupying this area was calculated. If average zonular fiber bundles are 10 μ and length up to 3 mm there is 113 mm^3 (0.113 mg) of zonular mass filling a volume of 230 mm^3 (0.230 ml). This is a sizable force when driven by a powerful ciliary muscle.

ZONULAR HYDRAULIC FORCES

In addition, certain hydraulic forces within the zonular syncytium come into play. This hydraulic force is to be differentiated from other hydraulic theories of accommodation, which theorize vitreous pressure.[5] The anterior and posterior zonular planes are well seen during cataract surgery and histologically. Fluid within the zonular syncytium, bounded by the anterior and posterior planes (which may have a more viscous consistency than aqueous) would produce a hydraulic piston toward the lens equator when the ciliary body contracts (Fig 4).

OTHER FACTORS

Other, often overlooked, factors that influence accommodation are that

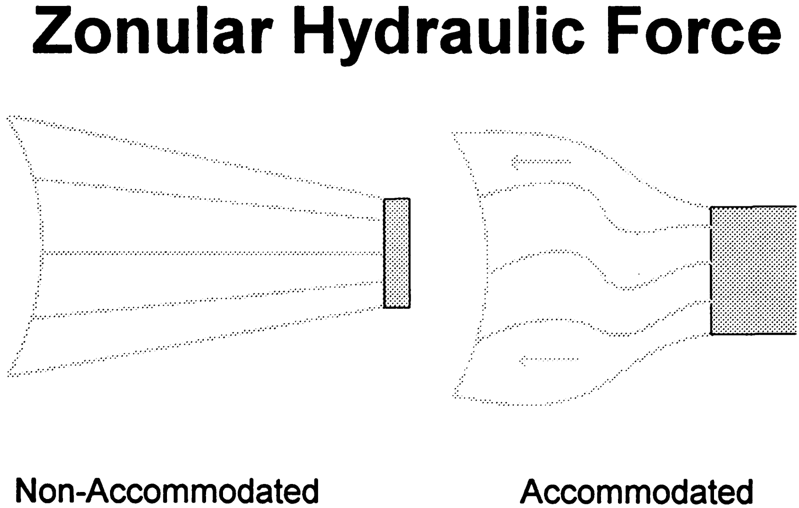

FIGURE 4
Zonular hydraulic forces.

accommodation is occurring in a fluid medium, in a pressurized (15 to 20 mm Hg) sphere, and utilizes a constrictive mechanical advantage, which, in effect, doubles the power, since each force directed toward the lens is opposed by an equal one.

CLINICAL OBSERVATIONS

The author has studied several cases of traumatic and spontaneous subluxed lenses, either with or without capsular wrinkling. Unfortunately, because the normal anatomy is disturbed, either from trauma or disease, the conclusions drawn from such cases already presented in the literature are always viewed with suspicion.

Three cases of capsular wrinkling in minimal to moderate traumatically subluxed lenses were studied (Fig 5) with both natural and pharmacologic accommodation (pilocarpine 6%) and nonaccommodation (atropine 1%) with precise slit-lamp and gonioscopic photographs. In these cases of capsular wrinkling, it is apparent that at the end point of both accommodation and nonaccommodation, there is very little appreciable difference between the tight capsular wrinkling fold height. However, the folds definitely flatten out between the two extremes. Exactly what conclusions can be inferred from

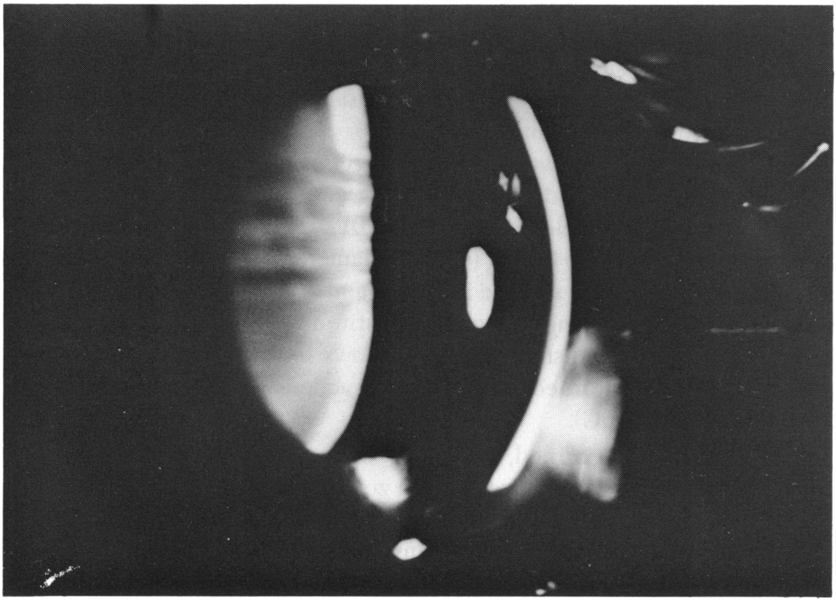

FIGURE 5
Capsular wrinkling in traumatic subluxed lens.

these observations is not entirely clear, but it would appear that during both maximal accommodative and maximal nonaccommodative states, there is tension applied to the capsule.

The author has also observed several cases of unilateral traumatic vitreous hemorrhage in the young (without lenticular or retinal damage), which, in each case, was removed by pars plana vitrectomy. Noting that none of these patients ever complained of difficulty with near vision or were ever fitted by their referring ophthalmologists with bifocals, I began to question the vitreous and hydraulic theories. Three postoperative pars plana vitrectomy patients (one teenager and two young adults with active accommodation) were tested for near points of accommodation without significant differences between their two eyes.

MECHANICAL MODEL OF HUMAN ACCOMMODATION

A mechanical model of human accommodation has been constructed that allows the observer to change the contractual abilities of the ciliary body and see the resultant changes on the zonular fibers (silicone tubes), which are adherent to a silicone gel-filled lens (approximately 10 times normal). A mechanical drawing to scale (top view and side view) of the model of human accommodation is shown in Fig 6A and B.

The external model (ciliary body) is constructed of Plexiglas stainless steel rods, silicone tubing, and nylon bushings and rollers. The lens (10 cm diameter) is a silicone gel-filled capsule (0.012-in thick). The zonular fibers (40) are made of silicone tubing (outside diameter 0.025 in) attached to the lens with medical-grade silicone adhesive and attached to the rods (ciliary body) through overlapping friction. The entire model fits into a saline-filled Plexiglas container (not shown), which allows the position to be changed (inverted, tilted, or turned) to verify the actions in fluid under varying circumstances (Fig 6C).

As the handles are turned, the ciliary body is simulated to contract or relax, with the resultant changes on the zonular fibers and lens. When the ciliary body is expanded to pull the zonular fibers and lens, similar to the Helmholtz nonaccommodation, the lens flattens, but the ciliary body must be actively expanded to keep it in that position—a rather unnatural position for it. From this position, as the ciliary body simulates contraction, the lens will become more rounded and return to a more convex surface similar to its natural resting state. At this point, the lens becomes free-floating. To test the Tscherning theory, the ciliary mechanism is again expanded but only to the point of minimal effect on the lens equator. While further tensing of the ciliary body expansion flattens the lens as in the previous experiment, it does not flatten the periphery less so than the central position of the lens. Even though this mechanical model is in a fluid medium, there is no way to test the various hydraulic theories that have been proposed.

It is very obvious, however, that as one constricts the ciliary body, the zonular fibers press or squeeze on the lens equator in a direct fashion, which increases the convexity of the lens. When this is carried to a maximum, there is at least 5 mm of anterior directional curvature. Fig 6D, E, and F depicts the changes seen on the zonular fibers and lens from contraction of the ciliary body.

One of the most dramatic aspects of the mechanical model is to observe the zonular fibers gradually curving as they are compressed between the constricting ciliary body and the lens. At the same time, the observer can easily see the lens becoming more convex.

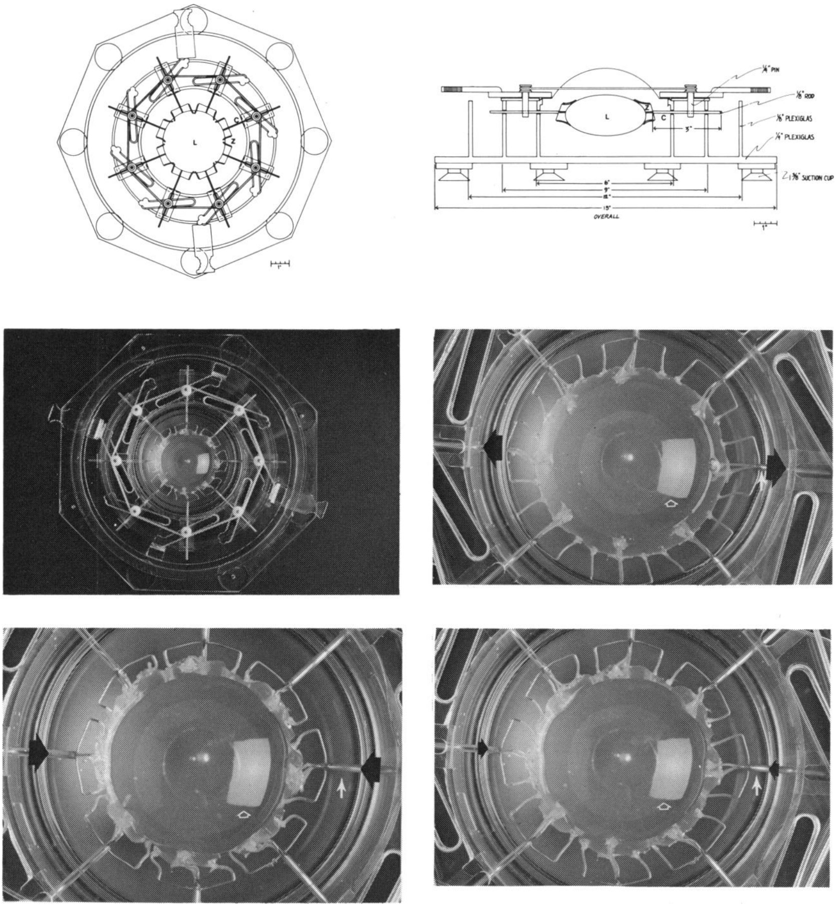

FIGURE 6
Mechanical model of human accommodation. A: Top view. L, lens; Z, zonules; C, ciliary muscle. B: Side view. C: Actual photograph of top view. D: Ciliary body, maximally enlarged. E: Ciliary body, mildy compressed. F: Ciliary body, moderately compressed. *Hollow arrow* = light reflex. *Solid arrow* notes ciliary body compression.

NEW THEORY OF HUMAN ACCOMMODATION

On the basis of a review of the scientific literature, clinical observations, and actions of the mechanical model of human accommodation, a new, previously undescribed, theory of an accommodation mechanism is proposed.

My interest in this subject began when I was an ophthalmology resident; a case of subluxed lens with capsular wrinkling was seen and the actions during accommodation did not conform to known theories. After studying additional similar cases, I reported at the 1983 Annual Meeting of the American Academy of Ophthalmology (AAO) that the direction of zonular forces seemed to be toward the lens periphery in accommodated and miotic states and away from the lens in nonaccommodated and cycloplegic states.[21] At the 1988 AAO meeting, I reported and displayed the previously described mechanical model.[22]

Although, Sir Stuart Duke-Elder once said, "Every possible hypothesis has been put forward to explain the rationale of accommodation," to my knowledge, there are no previous theories which suggest that the zonular fibers actually compress the lens periphery by transmitting the forces of the ciliary body directly to the lens at its equator.

Figs 7 and 8 depict this theory as an active process where the zonular fibers directly compress the equator of the lens (not to be confused with Tscherning's indirect compression of the lens periphery).

Fig 7 depicts the direction of forces proposed by this theory. In the nonaccommodated state, there are three possibilities: (a) the zonular fibers simply suspend the lens; (b) the zonular fiber forces are directed toward the lens and are opposed by the capsule elasticity; and (c) the zonular fiber forces pull the lens (as in the Helmholtz theory). Whichever mechanism best explains the nonaccommodated state is not important for the proposed mechanism of accommodation, since it postulates an active process of ciliozonular compression of the lens periphery in varying degrees.

This logical mechanism explains the inconsistencies of others' observations on an advanced active process consistent with our phylogenetic evolution. One of the inconsistencies, mentioned for completeness, is that the lens during accommodation is gravitationally moved and that at some point, it becomes tremulous. The author's new theory can explain these observations on the basis that the lens is suspended in the nonaccommodated phase, and as ciliary body contraction increases and the direction of forces is toward the lens, it actually goes through a zero state of gravity before the compression begins. Fortunately, all of these actions are occurring in a fluid-filled pressure-regulated container (the eye), which makes all of these movements very subtle and smooth.

Skeptics of this proposed theory, I believe, can only justifiably base their criticism on the fact that to date, there are no direct data on the compression or pushing force of the zonular fibers. Unfortunately, until more sophisticated microtransducers or other detection methods have been developed, we must be satisfied with indirect observations. A simple anecdotal

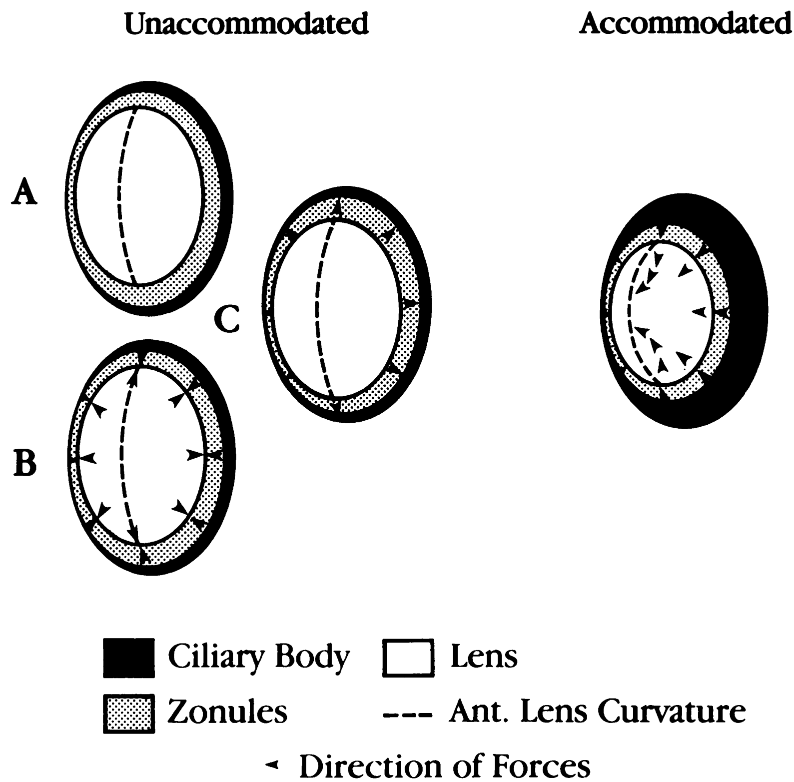

FIGURE 7
Theory of cilio-zonular compression of lens equator ("zonular compression"). Note that whether a, b, or c occurs, nonaccommodation does not affect proposed mechanism of accommodation.

analogy can be performed by taking a short length of a coarse hair (1 in or so) or an eyebrow. If one presses the hair against one's finger, the hair becomes curved as it is compressed and it is felt on the finger. This implies there is enough force (pressure) to excite feeling. It is not difficult to imagine that zonular fiber forces, albeit not as large as a hair, in combination and in a complete fluid medium, could transmit enough pressure to deform the lens 0.3 mm.

The author feels that what has been called the "relaxed" zonular fiber in accommodation may very well be a "compressed" zonular fiber.

Obviously, these observations, which I have made, constitute only a

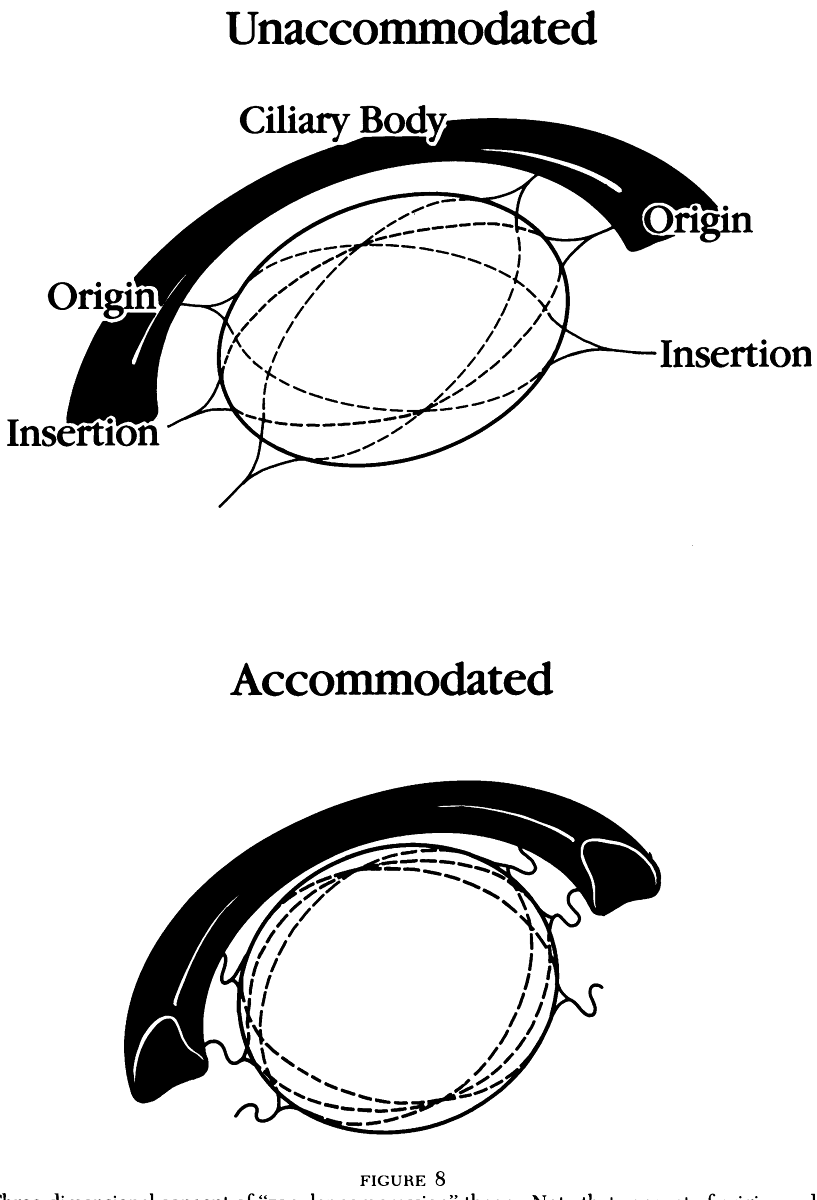

FIGURE 8
Three-dimensional concept of "zonular compression" theory. Note that concept of origins and insertions are from ciliary body to ciliary body 180° away. In accommodation, zonules fibers appear "slackened" or relaxed but are "compressed."

theory (a system of assumptions devised to analyze, predict, or explain the nature of a phenomenon). Observations have to be conceived before they can be proven or disproven. Science, which I'll define as orderly understanding through measurement, will eventually debate and define the plausibility of my theory.

To me, it seems logical that zonular forces can be directed toward the lens perimeter, augmenting capsular elasticity and explaining the inconsistency of other observations and theories.

ADDENDUM

I am indebted to Dr Thomas Kearns (see Discussion) for pointing out that a zonule (small zone) refers to the entire space around the lens occupied by zonule or zonular fibers. Through the years many have dropped the word "fiber," and the term "zonules" has incorrectly become synonymous with "zonular fibers." In accordance with this editorial suggestion I have gone through this manuscript and corrected "zonules" where I meant "zonular fibers."

ACKNOWLEDGMENTS

I wish to thank Mr Calvin Jackson for his advice and construction of the mechanical model of human accommodation. Kathy Green prepared the illustrations and Rita Bardin prepared the manuscript. Photographic reproductions were done by Cindy Monchilov. I am indebted to Jay Sprigg, physicist, for the mathematical calculations.

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DISCUSSION

Dr D. Jackson Coleman. Dr Wilson has most ably and cogently reexamined the theoretical and mechanical difficulties with the "traditional," or capsular, theory of accommodation as proposed by Hermann Ludwig Ferdinand von Helmholtz. Other theories, including my own, have been proposed to more satisfactorily explain the manner in which the human lens can quickly, accurately, reproducibly, and in concert with its fellow eye achieve a focusing range from distance to near. None of these theories hav been universally accepted—despite the impeccable logic, mathematical modeling, and measurement experiments that have (particularly with my theory) been used to support them. As Dr Wilson points out, vitreous, lens, and zonular pressure, as well as tensile forces, cannot at present be measured to everyone's satisfaction. Dr Wilson's theory proposes a novel mechanism that is based on compression of the lens equator by the zonules to satisfy the observed optical "rounding up" of the lens.

Several features of lens and ciliary outlined in the Wilson hypothesis are generally accepted. The lens has a thickened anteroposterior diameter, moves forward, and takes on a rapidly reproducible shape. The ciliary body contracts, and the ciliary ring moves forward. Other features have been demonstrated but not widely acknowledged, such as the pressure gradient between the anterior chamber and the vitreous in primates that supports a suspension theory ("hydraulic" in Dr Wilson's analysis; *Trans Am Ophthalmol Soc* 1986; 84:846-868.). The suspension theory also explains observed optical reproducibility of lens curvature.

The essence of the Wilson theory is a novel explanation of lens rounding and displacement that results by compression of the lens equator due to pressure on the zonules by the ciliary body. This concept is interesting but questionable. The zonule, like a chain, may be able to support or flatten the nonaccommodated lens through lesion (like a chain), but no evidence has ever been presented that it can act as a rod to compress the lens equator. In mechanical terms, it has not been shown in the experimental literature that zonules have measurable compressive and/or shear strength. As Dr Wilson has suggested, tensile strength may be an indicator of compressive or shear strength. It is in material such as bone where tensile and compressive strength are roughly proportional. However, in material such as nylon and viscoelastic fibers, this is not the case. Without sufficient rigidity, compressive and shear strength are not measurable quantities in these materials. For Dr Wilson to marshall support for his theory, he must provide some experimental evidence that the zonules possess sufficient rigidity to compress the lens.

I agree completely with the weaknesses of the the capsular theory that Dr Wilson has enumerated. However, I feel that the suspension theory that I have described successfully addresses these areas as well as others that relate to the rapid reproducible anterior lens curvature. In addition, it conforms to force analysis of zonule-lens-capsule mechanics. All cataract surgeons who have performed capsulohexis are familiar with the elastic and shear properties of the capsule: it tears like rigid Saran Wrap (or tomato skin) rather than like a stretched rubber glove.

The debate has continued for over 140 years in ophthalmology texts. Optometry texts appear to understand the optical relationship of the caternary suspension theory. Until we can more accurately measure the vitreo-zonular-lens forces in vivo in the human, the debate will continue.

Dr William Glew. Dr Wehrly, our senior resident, came up with the idea of examining accommodation by the MRI technique which Dr Coleman has also suggested. Dr Coleman's slide showed the nonaccommodated lens in an MRI image. I made a few suggestions to Dr Wehrly and we recently pursued this project. The volunteer is a 31-year-old resident and we used a 1.5 Tesla GE MRI with surface coils to enhance the image. These two slides show the unaccommodated lens and the lens after accommodation and, as you can see all the lens changes that Dr Wilson mentioned are present here. There is an increase in the anteroposterior thickness and a decrease in the transverse diameter in comparing before and after accommodation. The images also show a slight movement forward of the lens and slight decrease in the anterior chamber depth. Because of Dr Coleman's hypothesis we measured the distance from ciliary body to ciliary body but did not find any difference after accommodation, possibly because the ciliary image is not sharp enough to permit accurate measurement. But I think it is nice to be able to use the MRI to study this problem and as far as I am aware Dr Wehrly's project may be the first to demonstrate by MRI the changes in the human lens during accommodation. As we are considering submitting the study for publication, I would appreciate hearing from anyone who knows if there are any other published pictures like this. We did make some interesting measurements which support all the changes that you can see. We used the technique of best fitting curves to measure the anterior and posterior curves of the lens. We came up with a nonaccommodative power for the lens of 17.8 diopters, whereas after accommodation it was 23.1, a difference of 5.3 diopters due to the lens changes. Since the subject was focusing at about 15 cm (using approximately 6.5 diopters of accommodation), he might need just a little bit more than the 5.3 diopters of change that we measured in the previous slide. But that extra 1 diopter might be accounted for by the slight (0.3 mm) forward movement of the lens. Our conclusions were very much like the slide that Dr Wilson showed in the beginning of his talk. It is good to know that one more modern technique has confirmed previous evidence summarized so nicely by Dr Wilson.

DR GEORGE WEINSTEIN. As the primary discussant pointed out, the subject of accommodation is a matter of historical interest for most of us. Nevertheless, I think many of us are still fascinated by the effect of a series of fibers on the sphericity of a round object. In particular, I refer to the men's tennis tournament. Regrettably, last night the chair of the athletic committee neglected to mention the runners up and the winners of the tournament. Mr President, I would like to take this opportunity to ask you as members of this audience to join me in announcing the runners-up: Drs Spaeth and Yee and the winners, Dr Gutman and the author of this paper Dr Wilson.

DR J. TERRY ERNEST. I think this is a marvelous opportunity to ask the experts a question that I have had since I was taught physiologic optics. If you accommodate to a target lets say 1 m, the blur circle is in the center of the conoid of Sturm. Now if you move the target closer to the eye there will be more blur and if you move the target further from the eye there will also be more blur. My question is, how does the lens (accommodating mechanism) know which way to accommodate?

DR ROBERT DREWS. I began hearing very heated debates on the mechanisms of accommodation over 55 years ago, in my father's home. It was interesting at that time how much emotion there was and although the discussions have become a little more civilized these days I think there is still an emotional element involved here. Dr Wilson, I didn't understand the figures you presented. What percentage of the space around the lens is physically occupied by the zonules and what percentage is occupied by aqueous? It seems that the percentage got awfully high with zonules in some of the figures I saw. In 1957 in the meeting of the Midwestern Division of ARVO after dinner a lecture was given by Dr Leinfelder. He reported on work that they were doing in Iowa on transplantation of the human lens! The cataractous lens was removed from the patient and a lens obtained from an eye bank eye was implanted in the patient's eye. This paper was delivered with absolute seriousness. Only after he got going for a while did the audience begin to catch on that he was pulling our leg, and I must say Leinfelder never cracked a smile even to the end of this paper when he had people rolling in the aisles. But his final feat was to place the patient on eserine so the constricted ciliary body processes abutted against the periphery of the lens forming peripheral synechiae so that the patient was able to accommodate. He never published this paper.

Dr Thomas P. Kearns. Dr Wilson, I hope that you will not think that I am nit-picking but I would like to make one point. As a former editor of the Transactions I noted that a frequent error made by authors was the confusion of the words zonules and zonular fibers. I believe that in your presentation you mentioned that your model eye had 40 zonules. There is only one zonule in each eye although there are many zonular fibers.

Dr Sloan Wilson. I want to thank all the discussants and in particular Dr Coleman. Until we can actually put transducers inside the eye and make accurate measurements we all have to have some form of an indirect method to evaluate this process. I do appreciate the comments.

Dr Ernest, I cannot answer your question. Dr Coleman, if you know of a mechanism in the brain and how it happens to know that the conoid can be picked up and which way to go, I would be happy to hear about it. I think you've asked a question that may not have an answer. It may be trial and error.

Dr Glew, thank you very much for your interest in the subject and I look forward to reading in detail your paper when it is published. You certainly have shown that the earlier findings in accommodation are reproducible with modern technology such as the MRI.

Dr Drews, the percentage is high and I think it depends on how you view these calculations and what you consider as the diameter of the zonule and the zonule fiber. Regarding the zonule fibers, I talked to Dr Streeten and also Dr McCollough, who each wrote their AOS thesis on zonular anatomy. My question was, "How many zonular fibers are there?" and they said, "I don't know, what do you consider a zonular fiber?" So that was where my calculations originated. It was an attempt to get a rough idea of how many zonule fibers there are and how much mass there really is. If you look at it on a mass basis, Jack, maybe if you had 535,000 leaders you could push that trout back into the stream. So there is more mass than we might think, and there is more volume (relative to the lens) and with a two to one constrictive value, it may make it all possible. I don't know the answer, and obviously this is why we are all debating.

The comment from Dr Kearns is certainly correct and unfortunately I believe, as with many things in the English language, we tend not to be as accurate as we should.

In summary, I am delighted, at least, to have the opportunity to present this theory and I thank the AOS for accommodating me.