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THE PRESUMED AND APPARENT ROLE OF LENS ELASTICITY IN THE ETIOLOGY OF PRESBYOPIA

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Presbyopia is defined by the Dictionary of Visual Science[22] as "A reduction in accommodative ability occurring normally with age and necessitating a plus lens addition for satisfactory seeing at near, sometimes quantitatively identified by the recession of the near point of accommodation beyond 20 cm." Webster[24] and Dorland[5] attribute the disminution of accommodation to the "loss of elasticity of the crystalline lens" which is generally believed due to sclerosis, or hardening of the nucleus of the lens.

Thomas Young[25], who proved conclusively that the act of accommodation was mediated through the alteration in shape of the crystalline lens in man, commented, "It has been observed that the central part of the crystalline becomes rigid by age, and that this is sufficient to account for presbyopia"[26]. This remark makes it evident that the classic concept of the cause of presbyopia dates back even before 1860.

A statement by Donders[4] crystallizes the reasoning regarding lens sclerosis as the basis for presbyopia. "In the first place, it may be asked, in general, how and from what cause it is, that at so early a period in life, while all functions, and especially that of the muscles, are in a state of progressive development, the power of acommodation, which depends upon muscular action, already loses in extent? As it must be admitted, that the ciliary muscle has continued normal, and is therefore still in full force, we come readily to the inference that, at least in the first instance, the disminution is to be sought exclusively in the condition of the parts, which in accommodation are passively altered, and by no means in the state of those whereby the

* The contents reflect the personal views of the author and are not to be construed as official Air Force policy.

change is actively produced. Now the organ which is passively altered is the lens. Is the early disminution in the range of accommodation $\frac{1}{A}$ to be explained from this? We know that at an advanced time of life, the lens is firmer than in youth. I think. I may even assert that the increase in firmness commences at an early period. Now, it is in consequence of this greater firmness that the same muscular action can no longer produce the same change in form of the lens. It is therefore very probable that the early disminution of $\frac{1}{A}$ depends thereon".

Fuchs[11] differentiated between physical accommodation, the actual alteration of the lens, and physiological accommodation, the action of the ciliary muscle. The "myodiopter" was introduced by Flierenga[10] as a unit of the physiological component in accommodation, i.e. the contractile power of the ciliary muscle required to increase the refractive power of the lens by one diopter. Regardless of age, they believed, the same amount of ciliary contraction is required to produce a given change in the form of the lens within the limits that the lens can change form. With increasing age, less and less of the muscle force available can be utilized.

The reaction of 2013 subjects to homatropine was studied by Duane[6]; the drug produces a gradual paresis of the ciliary muscle. If the same amount of physiological accommodation is available regardless of age, then the young, who do manifest a close nearpoint of accommodation, should show an almost immediate recession in response to the cycloplegic, and the older individuals should not react until the physiological accommodation in excess to need had been absorbed. His results showed a more rapid reaction by the *older* people. Duane's findings led him to conclude that the "ciliary energy diminishes with age almost in proportion as the manifest accommodation diminishes".

This conclusion stimulated Henderson's[13] histological study of a series of eyes in successive decades from ages 10 through 60, and he reported progressive sclerosis of the interstitial tissue of the tensor and sphinctor divisions of the ciliary muscle. "Ciliary sclerosis" in the sixty year old was the description given to the muscle fibers imbedded and walled in by connective tissue, and thereby prevented from exerting their physiological action.

Henderson further noted that if lens is subluxated in an individual in advanced presbyopia it presents a myopic lenticular refraction. Although the nucleus becomes compressed and sclerosed, the cortex is never senile since new fibers are always being added to it, therefore regardless of age, the lens capsule will assume a more spherical form if it is released from tension.

A detailed study of the lens capsule convinced Fincham[8] it is highly elastic, and due to varying thicknesses, the lens would be flattened where the capsule was thickest, and would bulge where it was weakest upon relaxation of the suspensory ligaments. Maximum curvature occurs at the posterior pole for the capsule there is very thin; capsular thinning at the anterior pole is also seen, and in accommodation the thicker peripheral anterior capsule compresses the lens substance to a greater degree resulting in the assumption of the hyperbolic shape.

By an ingenious slit lamp arrangement, Fincham[9] photographed the unaccommodated and accommodated lens of a 22 year old individual who had suffered traumatic aniridia of one eye. It was evident that the nucleus as well as the cortex underwent a change in form, and this convinced Fincham that sclerosis of the nucleus is sufficient to account for the development of presbyopia.

Fincham[9] measured the radius of curvature of the anterior surface of extirpated levels from subjects aged 11 and 65, and found 5 mm and 9.5 mm respectively at the center of the surface. Since these lenses are assumed to be free of all restraint they are accommodated as far as the nature of the lens substance and capsule will permit. He therefore concluded "the loss of accommodation in the senile lens is due to the inability of the capsule to mould the more rigid lens substance into the accommodated form". Fincham expressed doubt that the recession of the near point at an age as early as it is manifested is the result of a loss of ciliary power due to increasing interstitial tissue among the muscle fibers. Graves[12] had reported an individual who had sustained injury to his eye, and the entire lens substance had been absorbed after trauma, leaving the empty transparent capsule in situ. Fincham observed the capsule response to accommodation when this individual was 40 years old, and he was convinced that the change which occurred could not be produced by a ciliary muscle with only "one-third of its original power".

To explain why full accommodation cannot be maintained indefinitely by a presbyope, and why optical help is preferred even when his accommodative nearpoint is shorter than his working distance. Fincham offered the following reasoning. "As the lens substance becomes harder with age, greater force from the elastic capsule will be required to produce a given change of curvature. This force, in view of the elasticity of the suspensions can only be applied by greater contraction of the ciliary muscle. Consequently, a force approaching the full capacity of the muscle may be required to produce maximal accommodation whether it be some 15 or 16 diopters in youth or only 1 or 2 diopters in presbyopia". The amplitude of accommodation, then, is limited by the balance between the freedom given the capsule by the contracting muscle, and the resistance of the lens substance to deformation.

Morgan and Peters[16] took issue with this explanation. If the only effect of the ciliary muscle is to release zonular tension so that the capsule can mold the lens, ciliary contraction in excess of capsular response should result in no increase in accommodation, but in a sinking of the lens under gravitational effect. Therefore, each diopter would require the exact same relaxation of the suspensory ligaments regardless of the degree of lens sclerosis.

The development of presbyopia as Morgan[17] explains it, is a result of sclerosis of the lens nucleus, sclerosis of the ciliary muscles, and a decrease in the mass of the ciliary body resulting from a loss of vessel elasticity, all due to aging. In 1946, Morgan[18] related the tension on the suspensory ligaments to the mass of the ciliary body which depends on the changes in blood volume in this highly vascular structure. Constriction of the blood vessels leads to a decrease in mass which increases the pull on the suspensory ligaments causing lens flattening. Ciliary contraction would necessarily need to be greater to make up for the decreased mass.

Although the etiology of presbyopia is still shrouded in the unknowns of the accommodative mechanism, lens sclerosis receives the major attention for the recession of the near point of accommodation with age. It has been stated that the lens loses its elasticity from the day of birth by a continuous process of sclerosis[23], but it must be conceded this would be exceedingly difficult to demonstrate experimentally. Duke-Elder[7] subscribes to the same cause and development of presbyopia commenting, "It follows that the power of accommodation gradually diminishes, a process which cannot be considered as abnormal and which proceeds gradually throughout the whole of life".

A number of interesting experiments and conclusions have been presented in the literature concerning correlations between accommodation and aging which are worthy of brief review.

Lancaster and Williams[15] investigated the effect of prolonged accommodation at or near the punctum proximum in subjects ranging in ages from 28 to 64 years. No surprise was expressed when it was found that the far point moved in. This was evident by the necessary addition of a minus spherical lens to a previously determined distance correction to again obtain maximum visual acuity at six meters; closing or resting the eyes brought recovery of the original refractive status in approximately ten minutes. The authors assigned the cause of the advancement of the far point to "contracture" of the ciliary muscle which was defined as "a state of maintained contraction" or retarded relaxation, i.e. at the end of the contraction the muscle does not return to its resting position but remains more or less shortened. This was distinguished from spastic rigidity

since applied stimuli still produced a quick further contraction, and on removal of the stimuli a rapid partial relaxation occurred, these being superimposed on the contracture. Here, then, the mechanics operating in latent hyperopia were made evident.

The effect of maximum accommodation upon the near point amazed the investigators. The expectation was for the ciliary muscle to fatigue after a short time interval and cause the punctum proximum to recede, but, in fact, the near point was found to be closer to the observer than initially after about one half minute. It continued to advance with repeated measurements for approximately half an hour at which time a gradual recession occured for most subjects. Even after an hour of reading, exerting full accommodation, subjects were able to read at a nearer point than at the start with remarkably few subjective symptoms. A curve plot for a 54 year old individual and a 13 year old revealed an interesting comparison. The presbyope initially showed 1.225 D of accommodation, and after five minutes of concentrated near point exertion 1.846 D was measured, an accommodative gain of more than 50 per cent. The youngster registered 11.75 D of accommodation at the beginning, and achieved 16.00 D at the end of the same time period showing about a 35 per cent gain.

The enhanced near point effect could not be explained on a muscular basis, for the ciliary muscle does not act directly on the lens, but on the suspensory ligament, and an excess contraction would only cause the lens to become more movable and sag under gravitational pull. The authors therefore concluded that under sustained ciliary muscular contraction for punctum proximum with resultant zonular relaxation, the lens gradually continues to become more and more convex. "Perhaps its surface does not become more convex; it may be that it is some of its deeper layers that gradually become more convex". Lens "viscosity" was employed to explain the initial rapid change followed quickly by a tapering off in a slower and slower change under continuously acting forces applied to the lens from without or within. The change in shape which results under the influence of stress is still within the limits of elasticity of the lens.

The effect of aging on the speed of accommodation was studied by Allen[1], and he noted that the time to accommodate seems to increase as the amplitude decreases. It was also found that for all ages the time to relax was decidedly faster than to accommodate. In an illustrated comparison, where amplitudes were equal the younger individual showed more rapid adjustments both in accommodation and relaxation. Allen employed a Badal optometer with the distant target set at theoretical infinity and the near target was variable as to distance. A timing circuit recorded the subject's reaction time response to accom-

modate or relax. The age spread of his subjects was 7 to 49 years. Kirchhoff[14] in 1941 had made accurate objective measurements of accommodation relaxation responses by photographing the changes in lens shape, but correspondence of findings was not discussed.

The faster changes in accommodation in younger observers were assigned to a lower viscosity of lens substance, or to a greater separation of the lens fibers bathed in viscose material, with preference expressed for the latter explanation. This would account for the decreasing rate at which the ceiling of accommodation is approached, indicating that the limit of stretch or deformation of the lens fibers has been reached. With the number of fibers increasing and the amount of viscose material decreasing with age "the amount of total 'slip' of the components within the lens must therefore be reduced while the friction between them is increased". This agrees in concept with the Lancaster-Williams conclusion expressed above.

The tables of accommodation of Donders and Duane apply to amplitudes of accommodation for mid-Europeans. In 1950, Rambo[19] offered that Egyptian, Greek, Italian and other people closer to the equator develop presbyopia earlier, and Scandinavian people later, than to the mid-Europeans. When ethnic Asiatic Indians and mid-Europeans were compared in an accommodative age study[20], it was found that practical equality exists for the two groups at age ten, but the Indian accommodative ability is less for all ages beyond. Considering an amplitude of 3 D as the criterion for presbyopia, Indians become presbyopic at age 38, while mid-Europeans reach this state at age 46. The findings were reported without conjecture as to the cause of the marked spread in accommodative amplitude between these groups. Said and Weale[21] found as much as a 5 per cent density difference in comparing the transmissivity of lenses in situ in Egyptian and British subjects aged 25 to 42 years; the former's lenses being yellower than the British. The sample was small and the cause for the increased density was not established, but the authors opined that a genetic basis was more likely than prolonged exposure to the sun. The possibility that the denser lens may be less amenable to deformation due to pigmentation adding to viscosity is suggested by this writer.

The development of presbyopia from five to ten years earlier in Negroes than Whites was reported by Covell[3] after analyzing "several thousand" clinical records of workers in the Panamá Canal Zone. Although the number of Caucasians who had spent their entire lives in the tropics were too few to draw a definite conclusion, he believed the clime might well precipitate a predisposition to lens sclerosis. Covell ruled out diet as a cause, for an abundant and easily obtainable

supply of natural food was available to the tropical natives. The higher percentage of degenerative diseases in the Negro population was offered as another possible factor in the earlier onset of presbyopia*.

The last correlation between presbyopia and aging to be reported here concerns a study made by Bernstein[2]. The fact that individuals differ in the age where retraction of the near point necessitates spectacle correction, indicated that presbyopia does not develop at the same pace for all persons. Working with the records of individuals whose death was attributed to natural causes, Bernstein found the association between expected length of life and the degree of presbyopia was stronger than in comparison with graying. Four thousand cases provided a mean presbyopic value for each age considered, and three classifications were made: those with greater presbyopia were considered the class of unfavorable risk (U); those of lesser presbyopia were considered the class of favorable risk (G); and the middle were considered class (M). At age 47, persons in class (U) had a life expectancy of 17.9 years, class (M) an expectance of 22.5 years, and class (G) and expectancy of 31.8 years based on 86 cases for (U), 83 for (M) and 83 for (G) respectively. The 13.9 year difference in life expectancy between classes (U) and (G) when only those persons who had died a natural death were considered indicated an obviously different risk existed. Natural death causes were given as "senility, heart, cerebral hemorrhage, arteriosclerosis and so forth". The differences between the three classes were evident at each age in equal magnitude when expressed in percent which was employed because of the reduced life expectancy at the higher ages. When the death causes due to different diseases were considered, the differences still appeared, but to a lesser degree. Although women exhibited the same mean presbyopic values as men, a more temperate mode of life was considered responsible for their greater life expectancy.

Summary

Although sclerosis of the ciliary muscle has been advanced as the cause for presbyopia, and the decreasing mass of the ciliary body due to reduced blood volume has been offered as a contributing factor in the etiology of presbyopia, the classical concept of a hardening lens nucleus of increasing proportion with aging is still the most universally accepted basis for presbyopia. The varying thicknesses of the human lens capsule, and the elastic property assigned to this membrane is deemed the responsible agent for the molding of the lens into its characteristic hyperbolic shape in accommodation. The lens contents do not play

* **M. J. Turner in England is attempting to collect data from practitioners in scattered points throughout the world to study the variations of accommodation according to climate and race. Infocus Nº 23, p. 8, Dec. 1961, London, England.**

a completely passive role, for the extent of response is governed by the viscosity or the relative freedom of the lens fibers in a viscous medium to intermesh as accommodative pressure is exerted by the capsule.

People native to hot climates apparently demonstrate an earlier onset for presbyopia than those living in more northerly regions of Europe. Both genetics and environment have been proposed for this predisposition, and since Egyptian lenses have been found to be yellower than British it may be that pigmentation affects the viscosity. It appears that life expectancy can be predicted by the rate of development of presbyopia; those individuals experiencing a slower progress are expected to enjoy greater longevity.

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