Aging of the Human Crystalline Lens and Presbyopia

Adrian Glasser, Ph.D.
Mary Ann Croft, M.S.
Paul L. Kaufman, M.D.

The primary function of the crystalline lens is to increase the vergence of light that enters the pupil after passing through the cornea. In an emmetropic eye, the refractive power of the lens will increase the vergence of light to focus on the retina. The young human crystalline lens also serves the function of accommodation whereby the optical power of the lens is increased through the action of a ciliary muscle contraction (see the chapter, "Accommodation and Presbyopia"). Preservation of these two important optical functions throughout life would require that the lens optical and physical properties remain constant. In fact, very little, if anything, about the crystalline lens remains unchanged with increasing age. The rapidity and inevitability of the changes in the lens are evident from both presbyopia, which begins early in life and results in a complete loss of accommodation roughly midway through the human life span, and from the high incidence of cataract in the elderly. Both presbyopia and cataract, in all likelihood, represent part of a larger continuum of events that occur with aging of the eye and lens and are not end points in themselves.

The Lens

The lens is shaped like an oblate spheroid, with an equatorial diameter approximately three times its axial thickness in the nonaccommodated state. The peripheral rim is called the *equator,* and its front and back surfaces at their intersection with the visual axis are, respectively, termed the *anterior* and *posterior poles*. The capsule surrounding the lens substance is a 15- to 30-μm-thick hyaline ectodermal basement membrane consisting of collagenlike glycoproteins.[1] It is thicker anteriorly than posteriorly and

in the midperiphery as compared to the polar or equatorial regions. The lens epithelium, a single layer of cuboidal cells, underlies the capsule anteriorly and equatorially. Mitoses in the equatorial epithelium produce elongated, flattened hexagonal cells—the lens fiber cells—that extend anteriorly and posteriorly and compose the lens substance. The lens fiber cells have extensive interdigitations that hold them together and prevent sliding of lens fibers against one another. The newest fibers are laid down closest to the lens surface, whereas the older fibers shrink, lose their nuclei, and become incorporated into the central part of the lens. Proteins make up approximately one-third of the total lens weight and consist of soluble fractions (85%) and insoluble fractions (15%). The adult lens substance is composed of a nucleus and a surrounding cortex that are differentiated based on optical zones of discontinuity, such as can be observed with a slit lamp.[2,3] The lens has a refractive index higher than that of the surrounding aqueous and vitreous, which increases from the surface of the cortex to the center of the nucleus. Independent of the capsule, the lens substance may well have its own elastic or viscoelastic properties, relevant to changing or maintaining shape.

The anterior and posterior lens surface curvatures can be described as paraboloid in shape, with a steeper curvature located centrally near the optical axis and the surfaces becoming progressively flatter toward the midperiphery. The curvatures, of course become substantially steeper toward the equatorial edges. This paraboloid, nonspherical anterior and posterior lens surface tends to minimize spherical aberration. The impact of the spherical aberration of the lens is further reduced because the iris covers the lens periphery, thus preventing the passage of light through this portion of the lens. Posterior to the lens lies the vitreous. A line of attachment of the lens to the vitreous (ligamentum hyaloidea-capsulare of Weger) forms a ring along the posterior aspect of the lens. The vitreous is thought to provide support and stabilization for the posterior surface of the lens.

Aging

The crystalline lens is an unusual tissue in that it continues to grow throughout life. This is not unique, as nails, hair, and other organs also continue to grow. However, in the case of the lens, its continued growth and other age-related changes have such a profoundly negative impact on the physical and optical performance of the eye that, more frequently than not, it is inevitably removed and replaced with a tolerably good prosthesis through which the world is viewed until death.

Growth

Lens growth occurs through the addition of epithelial cells migrating from the proliferative zone at the lens's outer equatorial edge. These cells

differentiate into elongated fiber cells extending toward the lens anterior and posterior poles. The result is a layering of the newer lens fiber cells over older ones. The effects of this continued growth of the lens can be assessed from both in vitro and in vivo measurements. Isolated lens weight increases linearly throughout life (Fig 1).[4–7] Lens wet weight at birth is approximately 180 mg and increases at a uniform rate of 1.33 mg per year, resulting in more than a 150% increase in the mass over one's life span.[7] Systematic differences in absolute weights exist between different studies, depending on whether fresh, fixed, or frozen lenses were weighed.

In vivo, lens axial thickness has been measured with A-scan ultrasonography and has been shown to increase linearly with age (Fig 2). Axial lens thickness can be measured with reasonable accuracy in the unaccommodated eye; however, differences in the rates of increase in lens thickness are seen among different studies comprising populations of different ages. Lens axial thickness may not increase linearly throughout the human life span.

Diameter

Clearly, the human lens continues to grow throughout life, as demonstrated by the increasing mass. However, lens equatorial diameter has been suggested either to increase with age or to remain constant during the adult years. Increasing diameter, as measured in isolated lenses after their removal from enucleated human eyes, is suggested to reflect growth of the lens.[8] This increasing lens diameter with age is believed to be the cause of presbyopia in a controversial new theory of accommodation and presbyopia that serves as the basis for which scleral expansion surgery is offered as a cure (see the chapter, "Accommodation and Presbyopia").[9,10] Until recently, lens diameter could be measured only in isolated lenses from donor eyes. Recently, however, magnetic resonance imaging (MRI) has been used for the first time to measure lens diameter in vivo.

To support the claim for an increasing lens diameter with age, many

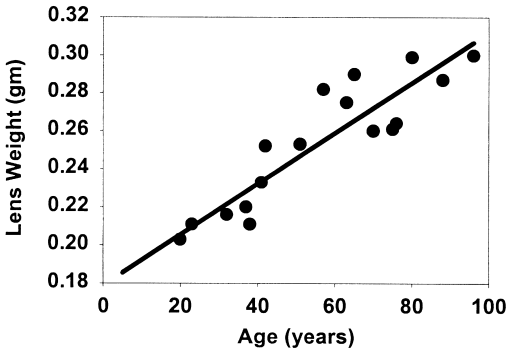

Figure 1. *The weight of the isolated human lens increases linearly throughout life. The relationship shown is from data obtained from wet weight measurements of 19 fresh, unfixed human lenses removed from human eye bank eyes ranging in age from 5 to 96 years.[7] (Reprinted from Glasser and Campbell.[7] With permission.)*

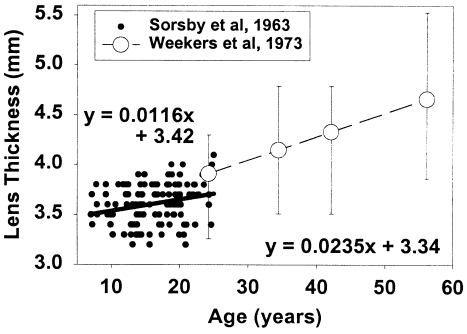

Figure 2. *Lens thickness as measured by A-scan ultrasonography in vivo. Sorsby and colleagues[49] measured 137 subjects between the ages of 7 and 25 years, and Weekers and coworkers[50] measured 159 emmetropic subjects between the ages of 20 and 60 years. The data from the latter study give only the mean (open symbols) and the max/min values (error bars) for four mean age groups. (Replotted from Sorsby and colleagues[49] and Weekers and coworkers.[50])*

reports[8,9,11] ironically cite the same original study by Smith[12] in which lens diameter was measured in isolated lenses after their removal from enucleated eyes.[12] All these studies[3,4,11,13] erroneously consider Smith's data to represent an age-dependent increase in lens diameter as it would occur in the eye. However, Smith was aware, as was Fincham,[14] that the diameter of the isolated lens does not reflect the diameter of the unaccommodated lens in the living eye. Smith identified that when the zonule was cut to remove the lens, the young lens assumed an accommodated form. Thus, when isolated lens diameter is measured, young lenses would have a diameter relatively smaller than that of the older lenses.[7,12,14,15] Early investigators had no other possible method by which to measure lens diameter and no possibility of measuring lens diameter in vivo; the latter can now be measured using high-resolution MRI.[16] The MRI measurements show no age change in unaccommodated lens diameter and an increase in *accommodated* lens diameters with age,[16] which is similar to the age-dependent increase in isolated lens diameter measured by Smith.[12]

■ Age-Related Changes in Optical and Biometric Properties

Few studies have measured optical changes in the crystalline lens with increasing age. This is in part due to the difficulty of measuring these properties in vivo and the difficulty in interpreting in vitro measurements on isolated lenses. In vivo Scheimpflug measurements of unaccommodated eyes suggest that the lens anterior and posterior surface curvatures increase with increasing age.[2] Although the optical influence of the cornea, through which the lens surface curvatures were measured, was computed to correct the lens anterior surface measurements, no such optical correction was computed for the optical effects of the unknown gradient refractive index on the posterior surface measurements. The accuracy of the absolute surface curvatures is uncertain; nonetheless, these results have led to what has been described as the "lens paradox."[17,18] This ad-

dresses the apparent incongruity between how lens surfaces become steeper with increasing age, yet near vision is lost with presbyopia. Increasing lens curvatures should produce an optically more powerful lens and an eye focused for near vision. However, with the progression of presbyopia, near vision is lost without compromising distance vision. This paradox has been resolved, theoretically (see later), by the suggestion that the lens gradient refractive index changes with increasing age to compensate for the increased surface curvatures.[18–20]

In isolated human lenses, focal length increased linearly with increasing age for 27 lenses from persons between the ages of 10 and 87 years (Fig 3).[15] In a different group of 19 lenses from persons ranging in age from 5 to 96 years, which included more older lenses with signs of early cataract, focal length increased up to approximately age 65 years and then decreased thereafter.[7] Despite the differences between these two studies, both show that, over the years during which accommodation declines to zero with the progression of presbyopia, the shortest attainable focal length of the isolated lens increases linearly. Because isolated lenses must be considered to be in a maximally accommodated state, isolated lens focal length is a measure of the shortest attainable focal length of the lens, or the *near point of the lens*. This linear increase in shortest attainable focal length of the lens with increasing age provides a plausible explanation for recession of the near point of the eye with increasing age. Interestingly, the lens focal length continues to increase, at least in one of these studies,[15] beyond the age of 50 years when accommodation is no longer present.

Spherical aberration of the lens also shows a systematic age-dependent change, from negative at age 10 to positive at age 86.[15] The extent of the lens spherical aberration is near zero at approximately 40 years of age. Although this systematic change in spherical aberration may have an im-

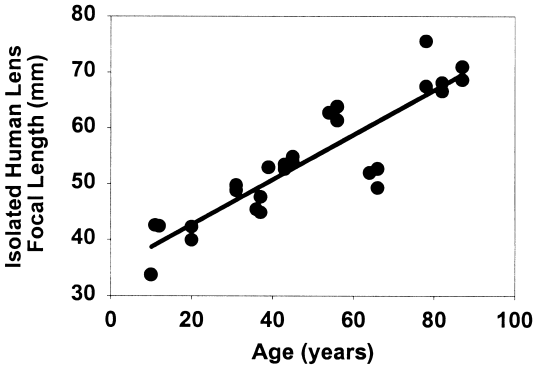

Figure 3. *The shortest attainable focal length of the human lens as a function of age. The relationship shown is from data from in vitro focal length measurements in 27 human lenses ranging in age from 10 to 86 years as measured with a scanning laser technique.[15] The focal length in the unstretched lenses represents the shortest focal length attainable, as the lenses are in their maximally accommodated form. The linear increase in shortest attainable focal length of the isolated lens may explain why the near point of the human eye gradually recedes with increasing age. (Reprinted from Glasser and Campbell.[15] With permission.)*

pact on vision, it should be emphasized that the measurements were from the full diameter of isolated lenses, much of which would be covered by the iris in the living eye. Further, without knowledge of age changes in aberrations of the cornea, it is difficult to conclude how the aberrations of the entire eye are affected and what, if any, impact the changes in lens spherical aberration have for vision. It is clear, however, that the systematic changes in lens spherical aberration must be due to alterations in the physical and optical properties of the lens. Young and old lenses are optically and physically very different.

■ Zones of Discontinuity

When observed in vivo with a slit lamp, bands or zones that scatter more light than the regions between the bands are observed in the human lens. These so-called zones of discontinuity differentiate the nuclear boundary of the lens as well as zones within the anterior and posterior cortex that have curvatures similar to those of the lens anterior and posterior surfaces. These zones appear to be an integral aspect of the aging lens, undergoing systematic changes in density and separation with growth and aging of the lens.[3] Slit-lamp images show that while the lens surface curvatures increase with increasing age,[2] the nuclear thickness remains relatively constant throughout life. Such images also show that the increase in lens thickness is due primarily to an increase in the thickness of the cortex of the lens.[21] With accommodation, however, nuclear thickness increases to change the shape of the lens actively, while the cortical thickness remains constant with accommodation.[22] Despite the increased lens surface curvatures of older lenses, the constancy of nuclear thickness with age suggests that the aged lens cannot be considered to be in an accommodated form.

Analysis of the zones of discontinuity of human lenses has shown that they correlate with growth and developmentally related production of more complex lens sutures throughout life, with each zone representing the site of a distinct generation of more complex suture patterns.[21] The presence of the zones of discontinuity and their age-dependent increase in light scattering may reflect a decrease in interfiber transport mechanisms; the latter may normally be augmented by the accommodative changes that the lens undergoes.[3] The more pronounced zones of discontinuity appear to correlate with the reduced deformability of the lens and the progression of presbyopia with increasing age, but the causal or consequential relationships remain unclear.

■ Changes in Refractive Index Distribution

The crystalline lens has a gradient refractive index that increases from the cortical surface to the center of the nucleus. Direct measurement of

the gradient refractive index is impossible to accomplish without disrupting the gradient being measured. Theoretical approaches have been used to study the gradient refractive index of the human lens and to suggest and demonstrate the feasibility of possible age changes. Several theories of presbyopia rely on changes in the gradient refractive index of the lens to maintain lens power with increasing age in the face of increasing lens surface curvatures.

One so-called disaccommodation theory of presbyopia suggests that the crystalline lens cannot be maintained in an unaccommodated state due to age changes in the zonular attachments at the lens equator (see the chapter, "Accommodation and Presbyopia").[23] Although the shape of the nucleus suggests that the old lens is not accommodated, the profound optical changes that the lens undergoes suggests there may be some regulation within the lens to maintain constancy of optical power and, hence, ocular refraction with age. Theoretical modeling studies show at least the feasibility of this approach[24] and have suggested that the increased lens thickness and more pronounced zones of discontinuity have a functional role in the maintenance of lens optical power.[17] Empirical studies using calculations from population data suggest that the refractive index gradient does change to become relatively flatter in the nucleus of older lenses and that this could account for a compensatory decrease in power of approximately 2 D, which matches the increased power due to increased thickness and surface curvatures.[25,26]

■ The Capsule and the Aging Lens

Human lenses undergo an age-dependent decrease in deformation when subjected to high-speed rotational forces.[27] In addition, the age-dependent decrease in capsular elasticity with increasing age[28] led to the suggestion that presbyopia is attributable entirely to changes in the lens, whereby the decreased molding pressure of the lens capsule fails to mold the increasingly resistant lens substance into an accommodated form.[29] Additional studies of the human lens capsule show an increased thickness up to age 75, followed by a decline thereafter. Capsule breaking strain, tensile strength, and elastic stiffness decrease with age, and elastic stiffness at 30% strain increased up to age 35 and decreased thereafter. The capsule becomes thicker, less extensible, and more brittle with increasing age.[1]

Clearly, because accommodation is mediated by the capsule surrounding the lens, some insight into the relationship between the capsule and the lens must aid our understanding of presbyopia. It is generally recognized that the accommodated form of the lens is achieved through elasticity of the capsule (see the chapter, "Accommodation and Presbyopia"). This is clearly demonstrated by removing the capsule from isolated

lenses (Fig 4). Measuring the profiles of lenses of various ages before and after removing the capsule provides an indication of how the capsule subserves accommodation and how this role changes with age. In young lenses, the capsule ensures that the lens is in a maximally accommodated state. Removing the capsule from young lenses shows that the lens substance undergoes a change in shape toward a more unaccommodated configuration: That is, the young lens substance absent of its capsule has a shape "memory" resembling a less accommodated form. This alteration in shape with decapsulation occurs to a lesser extent with increasing age. In the oldest lenses, removal of the capsule is without effect on lens shape. Optical measurements confirm this systematic age change, showing an increase in focal length with decapsulation, the amplitude of which decreases to zero with increasing age.[7] Because age changes in lens and capsule are known to occur, the effects on lens shape that occur with decapsulation are likely due to a combination of the age changes in both the lens and the capsule.

■ Loss of Accommodative Ability of the Lens

Human lenses also undergo an age-dependent increased resistance to mechanical stretching forces applied through the ciliary body and zonule.[30] Mechanical stretching experiments in conjunction with lens optical measurements have been performed to determine age changes in the accommodative performance of the human lens.[15] These experiments take advantage of the fact that the young human lens becomes accommodated when zonular tension is released,[7,15] and mechanical stretching

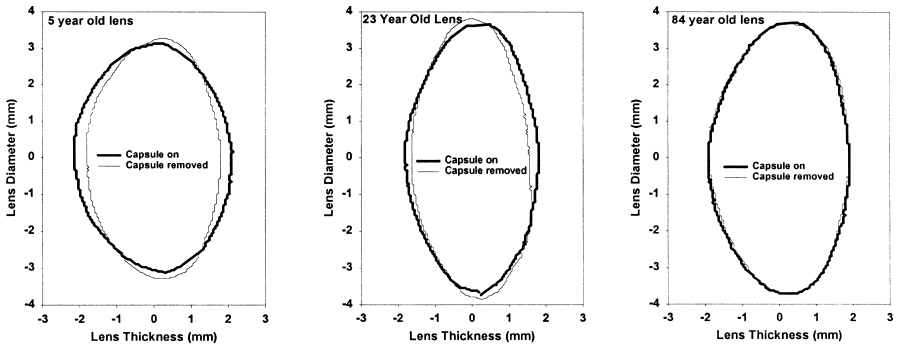

Figure 4. *Outlines of three isolated lenses (left to right: 5 years, 23 years, 86 years) with the capsule on (black solid lines) and after removal of the capsule (gray dotted lines).[7] For the 5- and 23-year-old lenses, removal of the capsule allows the lens to flatten and the equatorial diameter to increase into a more unaccommodated form (relatively more so for the younger than the older lens). In the oldest lenses, removal of the capsule is without effect on lens shape (data from Glasser and Campbell[7]).*

can then be used to disaccommodate the lens to cause an *increase* in focal length.[15] Young (11-year-old) lenses undergo a 14-D decrease in focal power with stretching (from completely accommodated to unaccommodated). With increasing age, the extent of the dioptric change with mechanical stretching is reduced, such that lenses older than 60 years are unable to undergo any change in lens power with stretching.[15] The age-related loss in ability of the human lens to undergo accommodative optical changes very closely matches the age-related loss of accommodative amplitude (Fig 5). This suggests that accommodation declines due, at least in part, to a gradual loss in ability of the human lens to undergo optical changes. The observation that lens accommodative changes in thickness and diameter are absent in presbyopes but that ciliary muscle function, although reduced, still is present also suggests that, at its end point, presbyopia involves an inability of the lens to undergo accommodative changes with the remaining ciliary muscle contraction.[16] This implies no causality for presbyopia, as each condition could be a consequence of the other (see the chapter, "Accommodation and Presbyopia"), but it does show that, ultimately, lens accommodation is completely lost even when some ciliary muscle function still is present.

■ Increased Hardness of the Lens

Classically, presbyopia has been attributed to increased sclerosis of the lens, whether or not this characterization is accurate. The word *sclerosis* has traditionally been associated with decreased water content of the lens. It remains equivocal as to whether a loss of water from the lens occurs and leads to a loss of accommodative ability, the relationship between sclerosis and hardness is uncertain.[31–34] No change in total water content of either

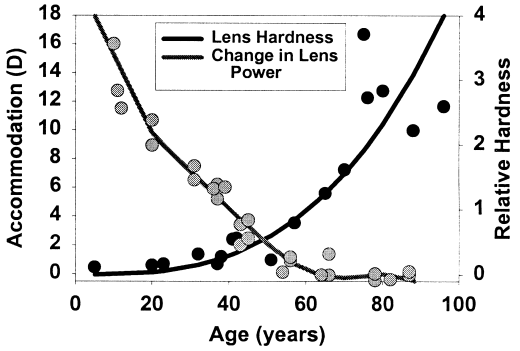

Figure 5. *While accommodative amplitude declines (left axis, gray line), the human lens undergoes an exponential increase in hardness (right axis, black line) with age. The gray line shows the relationship of data obtained by measuring accommodative optical changes in focal length while mechanically stretching 27 human lenses ranging in age from 10 to 86 years. The black line shows the relationship of data in which 19 fresh, human lenses, ranging in age from 5 to 96 years, were removed from cadaver eyes and underwent mechanical compression tests.[7] Lenses older than 60 years fail to undergo any accommodative optical changes with the same degree of stretching that produced a 14-D change in power in young lenses. Mechanical compression tests show an increase in lens hardness from birth with more than a fourfold increase in hardness over the human life span. (Replotted from Glasser and Campbell.[7,15] With permission.)*

the nucleus or the cortex was found with advancing age.[34] Siebinga and coworkers[35] suggest an increase with age, whereas Lahm and colleagues[36] suggest a decrease in the lens nucleus. Although the extent to which lens hardening occurs is debated in the literature, past and more recent evidence has unequivocally demonstrated increased hardness of the lens with age.[7,27,30] The more recent results show a fourfold exponential increase in hardness of the human lens that begins at birth and continues throughout life. The young human lens, which is capable of large changes in optical power, is soft and offers little resistance to mechanical deformation, whereas human lenses of increasing age show a reduced accommodative capacity and an exponentially increasing resistance to mechanical deformation. Although experimentally applied compressive forces are very different from accommodative forces on the lens, they clearly demonstrate an increased hardness with age. This increase in hardness continues well beyond the age at which accommodation is lost and does not necessarily correlate with declining accommodative amplitude (see Fig 5). Mechanical compression and accommodation are profoundly different processes, but the end result—loss of accommodation—is certainly predicted from hardening of the lens. The continued increase in hardness suggests that the age at which accommodation is lost may simply represent one time point on a continuum that is reached when the capsule can no longer mold the hardened lens with the remaining ciliary muscle contraction. According to this theory, presbyopia is simply a consequence of the gradual age change in lens hardness, the ultimate end point of which is advanced cataract near the end of one's life span. In this scenario, then, the question is no longer why humans develop presbyopia but why the lens becomes hardened.

Changes in lenticular deformability could occur consequent to dehydration, formation of various types of chemical or physical bonds between adjacent lens fibers, hyperpolymerization of proteins, or myriad other events. It is unknown whether these events happen causally or consequent to the development of presbyopia. Although lens hardening unequivocally occurs, the thesis that presbyopia is due to lens hardening or loss of lenticular elasticity is but one of many possible theories in the pathophysiology of presbyopia, each of which is supported by evidence. It is possible, for example, that the lens hardening may occur as a consequence of reduced accommodative effect on the lens consequent to reduced ciliary muscle efficacy. Certainly, further study is required to ascertain the cause of presbyopia and whether the progression of presbyopia can be slowed, prevented, or reversed.

■ The Lens and Accommodation Restoration

Much recent interest in presbyopia stems from consideration of the possibility of surgically restoring accommodation in presbyopes. Because

many theories of presbyopia consider various aspects of aging of the eye and lens, some discussion of the impact of aging of the lens on the surgical restoration of accommodation is presented here.

Scleral Expansion

Restoration of accommodation with the use of scleral expansion bands (SEBs) is based on a revisionist theory of accommodation that is not supported by recent experiments.[37] Presbyopia is suggested to be caused by gradual reduction of resting zonular tension at the lens equator, although this too is based on incorrect notions of equatorial growth of the lens (as discussed previously). Nevertheless, scleral expansion restoration of accommodation, either through relaxing radial scleral incisions (radial sclerotomy or anterior ciliary sclerotomy) or through the use of SEBs, relies on the premise that the crystalline lens in the presbyopic eye retains the capacity to accommodate. Scleral expansion does not restore accommodation as assessed by an objective infrared optometer.[38] The more than fourfold increase in hardness of the human lens,[7] the observation that although ciliary muscle contraction still occurs with an accommodative effort in presbyopes, no accommodative change in lens thickness or diameter occurs,[16] and the fact that after the age of 60 years the human lens cannot undergo optical accommodative changes[15] suggest that scleral expansion cannot restore accommodation and that, at present, the lens must be replaced if accommodation is to be restored. Thus, even in the unlikely event that scleral expansion surgery can somehow restore accommodation in early presbyopes, the continued progressive hardening of the lens and loss of ciliary muscle mobility, that occurs with increasing age[16] would ultimately and inevitably eliminate any accommodative gain. This, together with the inevitability of cataract development, must seriously limit any serendipitous effects that SEB placement may have on restoring near vision reading ability.

Phase I U.S. Food and Drug Administration clinical trials of scleral expansion surgery started in the year 2000 in the United States. Such operations also continue to be performed outside the United States as well, but still without objective postoperative assessment of accommodation. Some limited ocular aberration measurements are being performed, which may provide an explanation for some degree of functional near vision if preoperative and postoperative measures show an increase in corneal or lenticular multifocality, for example. However, aberration measurements are no substitute for objective measurements of accommodation, the physiological function that this surgical procedure is purported to restore. Accommodation can and should be measured objectively for assessing surgical procedures designed to restore this function. On the basis of the preponderance of experimental evidence, if accommodation

(i.e., a dynamic change in lens focal length due to ciliary muscle movement and lens capsular elasticity, as distinct from improved near vision through induced multifocality) is to be restored in presbyopes, it cannot be achieved through scleral expansion. Ultimately, if accommodation is to be restored, this should be accomplished by direct restoration of the accommodative ability of the lens, implantation of an artificial accommodative lens, or restoration of the accommodative performance of the ciliary muscle and its elastic attachments.

Polymer Injectable Lenses

One possible approach that has been explored experimentally in animals is injection of a silicone polymer lens into the capsular bag after phakoemulsification through a small capsulorrhexis. Some researchers have explored the surgical techniques required to inject a polymer into the capsular bag[39–42] and the efficacy of these procedures to restore accommodation in monkeys.[43–47] Although operations have been performed successfully, complications have been reported and have proved problematic.[48] Accommodation could not always be demonstrated optically due to secondary cataract, but slit-lamp videography and ultrasonography have shown accommodative changes in lens curvature and thickness and decreases in anterior chamber depth with pharmacologically stimulated accommodation.[47]

Hinged Haptic Lenses

The frequency and success of cataract surgery in which an intraocular lens (IOL) is placed in the capsular bag after phakoemulsification of the cataractous lens has provided the underlying motivation to restore accommodation. Several patents exist for IOLs designed to be placed in the capsular bag to provide some degree of functional accommodation. These approaches are based on replacing the presbyopic crystalline lens with an artificial IOL of fixed focal length that could, theoretically, be translated forward in the eye with an accommodative effort. One such lens, by ophthalmologist Stuart Cumming, M.D., has hinged plate haptics and is designed to translate in the eye with accommodation. Calculations relying on the placement of this lens in the capsular bag so that it is vaulted back against the vitreous suggest that some limited accommodation could occur if the lens vaults forward with an accommodative effort. The success and longevity of lenses of this type remain to be determined, but the frequency with which cataract surgery is performed and the growing presbyopic population suggest that many more lenses of varying designs will be proposed as prosthetic devices to replace the aging human crystalline lens, in an attempt to restore accommodation.

■ Summary

The human lens undergoes profound optical and physical changes with increasing age. The impact of these changes is evident in the extraordinary loss of the physiological function of accommodation roughly midway through the human life span and in the nearly inevitable development of cataract in the elderly. Various lines of experimental evidence show that age-related changes in the lens occur from birth and include increased mass, increased thickness, increased anterior and posterior surface curvatures, increased hardness, increased light scattering from the zones of discontinuity, possible changes in refractive index distribution, loss of ability to undergo accommodative changes, changes in spherical aberration, increase in the shortest attainable focal length, and decreased ability of the capsule to mold the lens. Under this barrage of insults due to aging, it is no wonder that presbyopia and, ultimately, replacement of the lens with an IOL are the norm. The reasons for the occurrence of these physiological changes are uncertain. The changes may be a cause or a consequence of presbyopia. Certainly, increased hardness, inability to undergo accommodative changes, and alterations in shape due to the capsule, together with an increasing shortest attainable focal length of the lens, all relate directly, either causally or consequentially, to presbyopia. Realistic surgical modalities aimed at restoring accommodation must consider these factors. Although some increased efficacy of the lens may be achievable serendipitously by unusual surgical interventions that either are in use or are being developed, clearly, if accommodation is to be restored, the crystalline lens must be replaced with a prosthesis that is more suited to the function of accommodation than is the aged human lens.

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