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SYNTHESIS

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Although the problems of presbyopia had been recognized by many before him, it was not until 1864 that Donders¹ first clearly charted the progressive recession of the near point with age that underlies these difficulties. For some centuries before, of course, single-vision spectacle lenses had been available to at least partly alleviate these problems; Franklin bifocals emerged around 1780 and trifocal were developed a few decades later.²

Where are we now? As the contents of this book make clear, substantial progress has been made, with a wide choice of nonsurgical and surgical approaches now available to help the presbyope. Some of these, such as presbyopic spectacle and contact lens corrections (see Chapters 13 and 14), are mature technologies. Others, including photodisruption and capsular refilling (see Chapters 27 and 28), are at an early stage of development. Some authors may be overenthusiastic about the potential of some techniques while others may be overly critical. Nevertheless, there is no doubt that this is an exciting time for all those concerned with enhancing the vision of presbyopes and that presbyopic patients can already benefit from an unprecedented range of available treatments. An outline regarding how to select the best approach to be used with the individual patient is provided in Chapter 29.

Herein, we attempt to assess the strengths and weaknesses of the progress made to date and the challenges that remain for the future.

THE NEEDS OF THE INDIVIDUAL PRESBYOPE

One theme, to which is referred by a number of authors (eg, Chapter 30), is the importance of paying proper attention to the needs of the individual patient when selecting a particular method of correction. What are the demands on the individual's distance and near vision? Are the needs of the presbyope limited to static near and near distance correction, or do they require clear vision over the continuous range of distances between distant and near? Is it important that any dynamic changes in ocular focus be achieved at speeds comparable to those achieved by the natural accommodation system? Under what environmental conditions are the visual tasks that are important to the patient carried out? What are the likely lighting levels, working distances, task contrasts, and subtenses? Lighting levels, for example, will influence pupil diameter, which is a crucial factor in determining the effectiveness of a variety of types of presbyopic

correction, particularly those based on the simultaneous-image (or simultaneous-vision) approach.

Closely related to these considerations is the question of the changes in vision with age (see Section II). Many of the methods of correction described in this book are best suited to meeting the needs of early presbyopes, where some accommodation is still active. What happens as the patient ages and as residual accommodation is no longer available? Is it straightforward to augment the near vision as appropriate to correct the continuing loss of accommodation in the earlier years of presbyopia or, in phakic individuals, to correct for slow changes in refraction? In this respect, insufficient attention has probably been paid to the long-term follow-up of patients who are initially happy with particular types of surgical correction. Does their near vision remain adequate after, say, 5 years, and are they still satisfied with their correction?

As new methods of correction become more established, there is a vital need for unbiased assessment of the long-term visual improvements for patients. Short-term benefits may be too high a price to pay for long-term problems.

CURRENT UNDERSTANDING OF THE BASIS OF PRESBYOPIA

It is clear that, although much has been learned about accommodation and presbyopia, doubt still exists regarding some aspects, which are of fundamental importance to the likely effectiveness of particular methods of presbyopia correction. Many of the methods that aim to restore some form of natural dynamic accommodation, in which the optical power of the eye undergoes change, depend on assumptions about the nature of the ocular changes leading to presbyopia. In particular, all designs of accommodating intraocular lenses (A-IOLs) assume that changes in the natural crystalline lens are the dominant effect underlying presbyopia and that the rest of the accommodative apparatus remains functionally unimpaired (see Chapter 20). If this is not true, or if postoperative changes affect the effectiveness of the remaining components of the natural accommodation system (eg, the capsule), then the “accommodating” corrections will not perform in accordance with their design concepts. It is of utmost importance that experience gained with such lenses is properly analyzed and reported to clarify these issues. Recent evidence from magnetic

resonance imaging suggests that, although the ciliary muscle remains active throughout life, the diameter of the ciliary ring reduces steadily with age. This would be expected to result in reduced zonular tension and to have implications for the possible effectiveness of techniques such as lens refilling or photodisruption (see Chapters 27 and 28), even if their other difficulties can be overcome.³ Further advances in the methods of imaging (see Chapter 34) should give better insight into such questions.

An even more fundamental question is why the amplitude of accommodation is lost at the observed rate. Donders’ data,¹ obtained some 150 years ago, are almost identical to those generally found today, despite great changes in nutrition, life expectation, and environmental factors. Some evidence is available that the onset of presbyopia might be affected by environmental factors, in particular temperature, or, perhaps, latitude or ultraviolet light exposure,⁴⁻⁷ but comparative studies of this type are bedeviled by poorly standardized methodology for measuring amplitudes or for defining presbyopia. Could nutrition or genetic factors be involved? Further work in these areas could give useful insights into whether the age of onset of presbyopia might be retarded by dietary change or manipulating living conditions.

NEURAL ADAPTATION

One of the phenomena that may play an important role in the success of strategies to aid presbyopes is neural adaptation.^{8,9} Various authors refer to it in this book (see Chapter 10) and elsewhere, but, as yet, comparatively few studies have attempted to explore its characteristics. The idea that patients can, over time, adapt to their somewhat blurred retinal images, so that their visual performance improves with time is an old one, and many have suggested that it contributes to some of the successes claimed by practitioners of the controversial and widely discredited Bates’ method for visual improvement.^{10,11} Be that as it may, it does appear that individuals “adapt” to their own ocular wavefront aberrations.

Several authors have shown that acuity improves after limited periods (30 to 120 minutes) of spherical defocus blur.¹²⁻¹⁵ Further, if an individual’s ocular wavefront aberration is held constant but is progressively rotated about the visual axis using adaptive optics, optimal visual performance is always obtained with the normal orientation of the wavefront error.¹⁶

There is evidence that keratonic patients adapt to their own aberrations.^{17,18} Chen et al¹⁹ found that a better visual performance was obtained when some ocular aberrations were retained rather than corrected, which is the opposite of what would be expected. Interestingly, Jung and Kline²⁰ have demonstrated that older patients are better than younger patients at recognizing blurred targets, an effect of which they attribute partly to smaller pupil sizes, but they also attribute it to experience-mediated neural compensation.

In light of these findings, further work is desirable on the phenomenon of adaptation in the context of presbyopic corrections, particularly the extent of its effectiveness and its time course.

In the spectacle lens field, attention has been primarily focused on adaptation to the spatial distortions and apparent movement phenomena experienced when a varifocal or astigmatic correction is changed. Little work has been done to explore the extent to which adaptation can improve vision in presbyopic contact lens wearers or after refractive surgery, particularly with simultaneous-vision approaches. The work of Wang et al,¹⁴ for example, suggests that depth of focus (DOF) may significantly improve after periods of blur adaptation. In clinical work, although there are frequent claims that vision improves after some weeks or months, this is rarely quantified in terms of direct measures of performance and may simply relate to a progressive acceptance of slightly blurred vision, with no real change in performance.

One slightly different, but related, phenomenon is described by Pérez et al.²¹ Somewhat paradoxically, they found that contrast sensitivity in the presence of scattering and spherical aberration could be better than that found with either scattering or spherical aberration alone. This may have implications for the correction of older eyes that suffer from substantial levels of light scatter (see Chapter 9).

DYNAMIC EFFECTS

The properties of the normal fluctuations of accommodation in the younger eye have been fully discussed in Chapter 5. The existence of such fluctuations means that, although the mean level of focus of the eye may be in error during observation of a particular target, the target may be resolved at some point when the fluctuation takes a favorable value and temporarily brings

the retinal image into better focus. Moreover, various authors have suggested that the fluctuations provide an important signal for the accommodation control system, which helps to maintain the steady-state focus of the eye.^{22,23} This raises interesting questions about the temporal characteristics of the “accommodation” offered by A-IOLs, lens refilling, lens photodisruption, or other techniques. In all of these techniques, the dynamics are likely to differ from those conferred by the natural crystalline with its unique biomechanical characteristics. If indeed the normal fluctuations are of importance, will their possible absence, or very different temporal characteristics, influence the maintenance of the restored accommodation? Again, will the dynamics of the accommodation response change? The few studies in which accommodation dynamics have been measured with A-IOLs suggest that responses are limited in magnitude and are relatively sluggish, but these characteristics need to be explored in more detail in the future.

ASSESSING VISUAL PERFORMANCE

The need for improved methods for assessing visual performance with presbyopic corrections has been strongly emphasized in Section VII. Simple measures of distance and near acuity, while of interest, may provide only a partial indication of the effectiveness of a particular type of correction and may be subject to the testing conditions employed. One of the simplest methods of improving measured near acuity is to increase lighting level, where pupil contraction will substantially improve DOF and hence acuity.

Many complaints from patients originate in visual problems under low lighting levels. Thus, one aspect of visual performance that deserves to be more regularly investigated is that achieved under mesopic conditions, such as in terms of acuities, contrast sensitivities, and, perhaps, dysphotopic phenomena.

An underexplored area of particular interest, in relation to visual fatigue, is the way in which, in younger (around 40 to 50 years) presbyopes, the limited available objective amplitude of accommodation interacts with simultaneous vision or monovision corrections. Is some accommodation exercised for all near targets, or do patients accommodate only when the target is too close for their correction to be capable of providing clear vision?

CURRENT AND FUTURE CORRECTIONS

The wide range of established, experimental, and possible technologies available for presbyopic correction has been thoroughly discussed in Sections VI and VII. We note that corneal inlays, in which an easily removable synthetic lens is placed under the corneal epithelium, have not as yet reached a stage of development to make them viable.^{24,25}

Several potentially exciting new approaches are in a relatively early stage of development. One class of these are corrections whose power can be electrically varied in either a stepwise or continuous fashion. Liquid-crystal technology forms the basis of many of these corrections, with the refractive index of the liquid-crystal material being changed by application of an appropriate electrical field to produce the required power variation. The earliest designs were intended for spectacle use. Initially, Fresnel lens designs were explored,²⁶ but it appears that diffractive designs have a greater potential.^{27,28} One such design, in which the bifocal segment is a switched addition, is commercially available (emPower). Contact lenses based on the same principles are also being explored.²⁹ Liquid lenses may provide an alternative route to a variable power correction, although at present their aperture remains limited.³⁰ Whether it may be possible to introduce an appropriate electrical signal within the eye to control the power of an IOL is not yet established.

It is also interesting to note that there is currently a re-emergence of an old concept for varying the power of full-aperture spectacle lenses—a liquid is pumped in or out of a lens with a flexible surface to change the surface curvature and hence the lens power. One version, intended for third-world distance vision correction, is designed to be adjusted only once and then to be fixed in power³¹; another, however, is marketed as a variable power spectacle for presbyopes, with power changes being actuated by a mechanical slider (Superfocus, Van Nuys, CA).³² A surprisingly effective variable-power spectacle lens based on the Alvarez principle, which uses lateral translation of a pair of lenses with surfaces following a cubic curve to vary its power, has also been developed (FocusSpec, Focus on Vision, Eindhoven, The Netherlands). A translation of a few millimeters gives a power change of up to 4.00 D. At present, this is incorporated in spectacles designed with the intention of providing very cheap, customized corrections for developing countries, but, in a more refined and solidly engineered form, it

could easily be developed into a viable variable-power presbyopic correction. One weakness, however, of spectacles of this type is that their construction allows only a limited range of frame geometries to be available.

A further interesting development, which is now under active investigation, is the concept of increasing DOF by phase-apodizing the pupil. It involves the formation of binary annular phase rings, having small variations in optical depth equivalent to half a wavelength, on the surface of a lens to produce an enhanced DOF through the manipulation of the phase differences along the optical axis between light from different points in the pupil.³³ The aim of phase-apodizing the pupil is to give a single, dioptrically extended “adequate” focus rather than the discrete pair or multiple foci achieved with diffractive lenses. Preliminary work has been carried out on spectacles³⁴ and contact lenses,³⁵ but it appears to be similarly applicable, with suitable allowance for the difference between the refractive indices of the adjacent medium, to the surfaces of IOLs. Although there is some loss in image contrast, substantially extended DOFs have been achieved in preliminary trials, with presbyopes achieving good distance and near vision when observing through the lenses.³⁶ This approach appears to be promising.

The attractive idea of using a uniaxial birefringent material, with its optic axis in the plane of the IOL, to construct a full-aperture simultaneous-vision bifocal³⁷ has yet to be followed, although some patents have been taken out. Such a lens would have an addition that is independent of pupil size. The basic concept is that the lower of the 2 ordinary and extraordinary refractive indices of the birefringent material provides the basic power of the lens, and the higher index provides the same power plus that of the addition.

Finally, we note that the availability of adaptive optical systems is making possible the exploration of the effects of a variety of different magnitudes and types of aberration on visual performance.³⁸⁻⁴¹ Using the adaptive system, the aberration of the individual patient is first compensated for, and then the required amount of aberration is added. This method allows the performance of new designs of lenses, ablation patterns, or other corrections to be simulated without actually having to make the lens or carry out the procedure. This should greatly accelerate the process of producing optimized corrections. As yet, most studies have been carried out monocularly, but it should be possible to extend studies to the binocular situation so that the effects of monovision or other interocular differences can also be included.

ENVOI

Much of this book is devoted to the fundamentals of accommodation and presbyopia and to current methods for giving presbyopes better vision over as wide a range of distances as possible. However, as Chapter 1 notes, there are probably some 2 billion presbyopes in the world. Only a fraction of these individuals have received any aid to improve their vision, and, of those who have, a still smaller fraction has access to the wide range of approaches described in this book. Much remains to be done!

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