New concepts in accommodation and presbyopia

Novos conceitos em acomodação e presbiopia

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ABSTRACT

The authors conducted a review of classical and conflicting theories of accommodation and presbyopia. They make a critical comparison with the findings of magnetic resonance imaging (MRI) that have been developed in recent decades. Based on these studies, formulates a new approach on the subject, shifting the focus of the discussion of the lens to the posterior pole of the eye.

Keywords: Ocular accommodation ; Presbyopia

RESUMO

Os autores revisaram as teorias clássicas e conflitantes sobre acomodação e presbiopia. E as compararam criticamente com os achados de imagem por ressonância magnética (MRI) que têm se desenvolvido nas últimas décadas. Baseado nestes estudos, formulam uma nova abordagem sobre o tema, mudando o foco da discussão do cristalino para o polo posterior do olho.

Descritores: Acomodação ocular; Presbiopia

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INTRODUCTION

The mechanism of accommodation has been one of the most researched in the last century and probably the biggest mystery surrounding the modern ophthalmology. Accommodation refers to the process whereby chances in the dioptric power of the crystalline lens occur so that an in-focus retinal image of an object of regard is obtained and maintained at the high-resolution fovea[(1)]. Although lenticular-based focusing was first proposed by Descartes, it was Thomas Young who initially demonstrated that changes in the crystalline lens itself were responsible for such focusing changes, and Helmholtz, who advanced the first basic but reasonably accurate explanation on the accommodative process[(2)].

Hermann von Helmholtz, graduated in physics, studied the lifetime optics human. Based on anatomical and physiological findings, noted that during accommodation the ciliary muscle to contract and there was an increase in the thickness of the crystalline lens, causing a greater power of convergence and focusing the image on the retina, when approaching an object in the eye[(3)].

However, in the last decade, exams with magnetic resonance imaging (MRI) of last generation have shown that the theory of Helmholtz not explains many consistent findings observed in these tests[(4)]. On the other hand, there is no other competing theory to explain the accommodation unequivocally. Any theory to explain the physiology of accommodation must necessarily describe all the changes occurring eye from the viewing of an object near the eye until its complete focus on the retina. It must also explain the changes found during the aging eye, especially after 40 years with the onset of presbyopia. Presbyopia refers to the slow, normal, naturally occurring, age-related, irreversible reduction in maximal accommodative amplitude (i.e., recession of the near point) sufficient to cause symptoms of blur and ocular discomfort or asthenopia at the customary near working distance[(2)].

In general, the set of theories proposed to explain the changes that occur in the eye resulting in presbyopia is grouped into three categories: theories based on the lens and capsule, which consider changes in the elasticity and compliance of the lens and capsule; extra lenticular theories which consider changes in the ciliary muscle and choroid, and geometric theories, which consider changes in the zonular attachments to the lens[(5,6)]. They all end up canceled by the complexity of the mechanism of accommodation and the lack of confirmation by imaging.

In 1965, the American Committee on Optics and Visual Physiology adopted the slogan:" Put Helmholtz back into Ophthalmology"[(7)]. The current state of research on the subject shows that the classical theory of Helmholtz is based on serious errors; however, there is another theory to replace it. Based on these facts and in the long history of studies on the physiology of accommodation in the last centuries, the authors make a great and thorough review of the literature on the subject, emphasizing what is already proven and that is no longer.

History

Reflex accommodation is commonly modulated as a feedback system, which operates to increase or enhance the luminance contrast of the retinal image. When the setting changes from far to near target, each eye accommodates and both converge in the interest of maintaining binocular vision. Historically, the existence of an accommodative mechanism was first demonstrated by Scheiner (1619)[(7)]. In their experiment, done on a card where objects are seen at a variable distance through pinholes contained in it, he proved that in the eye there is a mechanism controlling the focus adjustment. However, the true explanation of this classic experiment was offered by William Porterfield (1759), which suggested that accommodation as a result of changes in the lens. Other possible explanations have appeared in this context[(7)].

Albrecht von Haller (1763) considered that the contraction of the pupil diminished circles blurred enough to explain the phenomenon, a mechanism similar to a camera obscure which is present in some animals[(7)]. Some authors have suggested that the elongation of the eyeball caused by contraction of extraocular muscles would be responsible for accommodation[(7)]. The original theory of Kepler (1611) which referred to changes in the focus of vision obtained with the antero-posterior movement of lens (as occurs in some fish), received support from various observers, despite being established by several authors that such movements (around 10 mm) are not found in mammals, invalidating this theory[(5)]. Another possibility, that accommodation was related to changes in lens shape, it was suggested earlier by Descartes (1677)[(2)]. Much later, Helmholtz (1853-1856)[(3)] was able to demonstrate that the act of accommodation provided by the ciliary muscle was accompanied by an increase in curvature of both sides of the lens and an increase in its thickness.

Helmholtz[(3)] noted in 1855 that the center of the lens increases in thickness during accommodation. This simple observation led to the theory of eye accommodation, most accepted by most global ophthalmic community. It has also generated heated debates throughout the twentieth century and will probably be a matter of controversy in the coming years. The main reason these debates is the complexity of the subject studied by hundreds of researchers; if there are no studies that conclude definitively in favor of the Helmholtz theory, it is also true that there is none to deconstruct it.

According to Helmholtz[3], when the eye accommodates, the ciliary muscle contracts, reducing the zonular tension, leading thus to increase the space between the ciliary body and lens equator. This reduction of forces applied at the equator of the lens allows its tensile elongation, causing increases in the antero-posterior diameter, in its thickness and in its optical power. For Helmholtz[3], the act of accommodation is the result of ciliary muscle contraction that reduces its diameter and relaxes zonular tension. This allows young crystalline resume their original forms of highly curved and high optical power to focus near objects on the retina. When accommodation ceases, the ciliary muscle relaxes and returns to its form unaccommodated; zonular tension is again increased and the lens is pulled at the equator, increasing its focal length (Figure 1).

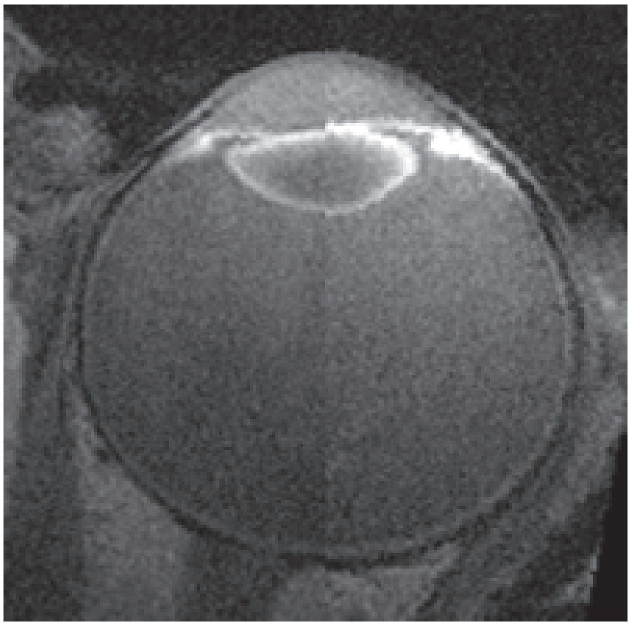

Figure 1: Shows the mechanism of accommodation in human (with permission, from: Strenk SA, Strenk LM, Semmlow JL, DeMarcoJK. Magnetic resonance imaging study of the effects of age and accommodation on the human lens cross-sectional area. Invest Ophthalmol Vis Sci. 2004;45(2):539-45)

The Flaws Found in Helmholtz's Theory

Currently, imaging studies confirm that most of the observations of Helmholtz actually occur, even advocated for over a century ago. It is also the only theory that explains, reasonably, the onset of presbyopia with the aging eye and loss of natural elasticity of the tissues that make up the accommodative apparatus, including the structures surrounding the lens. However, there are some details that the Helmholtz's Theory does not explain:

The anterior dislocation of lens

In the comments Helmholtz[3] had a classic experiment in which the author observed with the naked eye, lateral to the eyeball of a patient (through the cornea), the displacement of the anterior portion of the lens into the anterior chamber (Figure 2). According to the Theory competitor Tscherning[8], this shift would be promoted by the action of the vitreous, causing the forward movement of the lens to the anterior chamber.

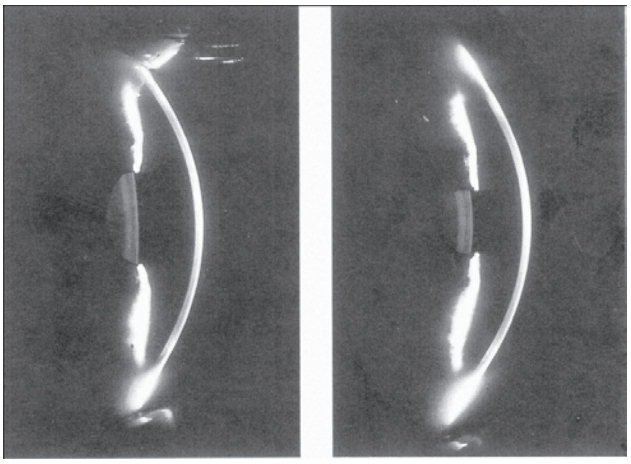

Figure 2: Shows the displacement of the anterior portion of the lens into the anterior chambre (with permission, from: Brown NP, Koretz JF, Bron AJ. The development and maintenance of emmetropia. Eye (London). 1999;13(Pt 1):83-92)

Imaging (MRI) has shown the anterior displacement of the root of the iris, the zonule and the equator of the lens during the accommodation process (Figure 3) and this motion is limited in presbyopic monkeys[4].

These data demonstrate that, contrary to that suggested Helmholtz[3], the lens does not remain static during accommodation, but moves the block (with adjacent structures) forward towards the cornea.

The paradox of lenses

The paradox of the lenses is a fact cited by many authors, but specifically discussed by Koretz and Handelman[9] and Brown et al.[10], who has no support in the literature for any of the theories known so far for the mechanism of accommodation. Figure 4 shows the evolution of the accommodation capacity of human throughout life, whereas the figure 5 shows the growth in thickness of the lens during the same period.

According to the proposition of several authors, including Brown et al.[10], the thickening of the lens (Figure 5) should increase the power of accommodation of the eye (increasing convergence of light rays by the lens)

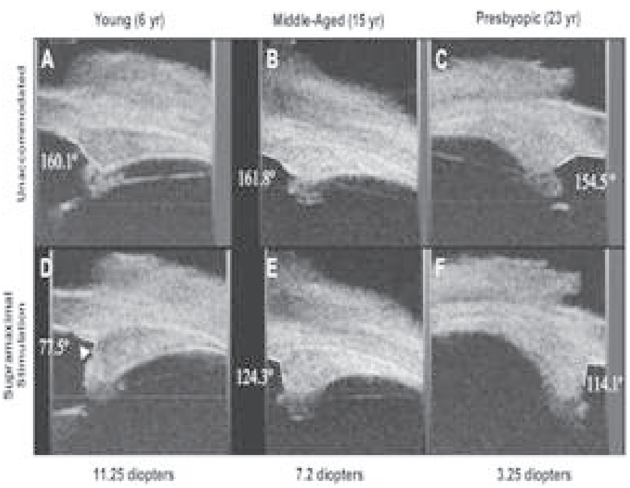

Figure 3 : Shows the anterior displacement (block) of the lens and iris (with permission, from: Strenk SA, Strenk LM, Semmlow JL, DeMarco JK. Magnetic resonance imaging study of the effects of age and accommodation on the human lens cross-sectional area. Invest Ophthalmol Vis Sci. 2004;45(2):539-45)

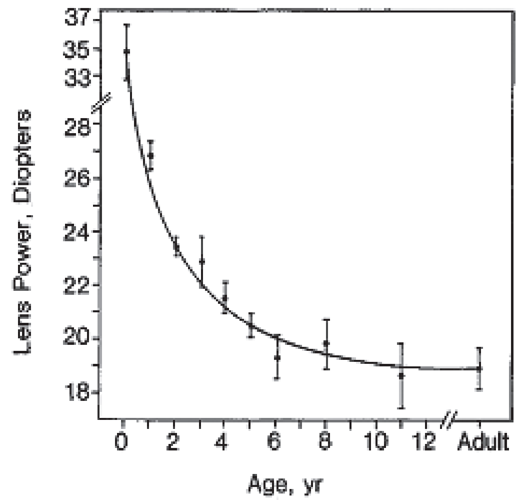

Figure 4: Age of humans X development of accommodation (with permission, from: Brown NP, Koretz JF, Bron AJ. The development and maintenance of emmetropia. Eye (London). 1999;13(Pt 1):83-92)

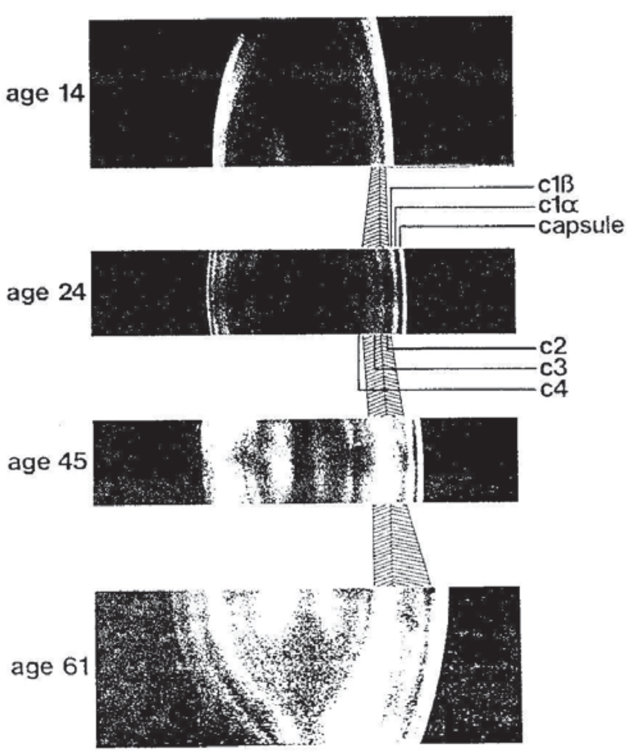

Figure 5: Age of humans X thickening of the lens.(with permission, from: Brown NP, Koretz JF, Bron AJ. The development and maintenance of emmetropia. Eye (London). 1999;13(Pt 1):83-92

and not decrease, as shown in figure 4. This fact is a paradox, frontally contrary to the Theory of Helmholtz. Moreover, this thickness would also generate a myopic eye, especially after 40 years, which is not proven in clinical practice.

The mechanism of the ocular emmetropization

The mechanism of ocular emmetropization, which is able to produce emmetropia from eyes originally born hyperopic (small), occurs during the first year of life of vertebrates and has been extensively studied, in recent decades. We know today that the emmetropization is linked directly to the mechanism of accommodation and the feedback that operates to increase or enhance the luminance contrast of the retinal image, as cited earlier. This fact was unknown at the time of Helmholtz and thus there is no report that correlates a mechanism other. But today we know that both mechanisms are intimately linked[9-13].

The classic experiments of Hung et al.[12,13], with placement of positive and negative lenses ("defocus" positive and negative, respectively) over the eyes of monkeys have shown that you can change the refractive state of eyes in minutes. Moreover, the posterior pole of younger eyes move with greater amplitude in the search for image focus, as shown in Figure 6.

The lens was finally incorporated into the ocular tissues in fish, 500 million years ago; were, probably, the first animals to have contact with the light of the ocean surface[14]. These animals were able to capture the underwater light stimulus through primitive eyes, containing cells with photosensitive pigments within a cavity rudimentary. The presence of light originated, initially, a high adaptive advantage to these species

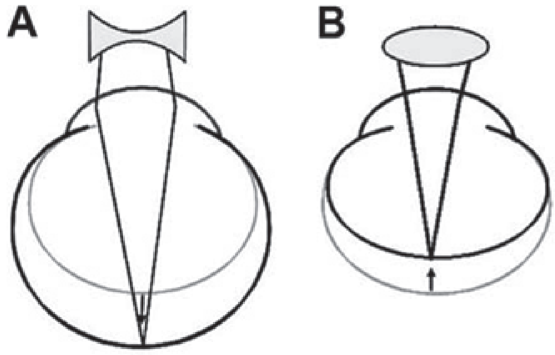

Figure 6: Defocus: A) negative; B) positive (with permission, from Hung LF, Crawford MLJ, Smith EL. Spectacle lenses alter eye growth and the refractive status of young monkeys. Nat Med. 1995;1:761-5)

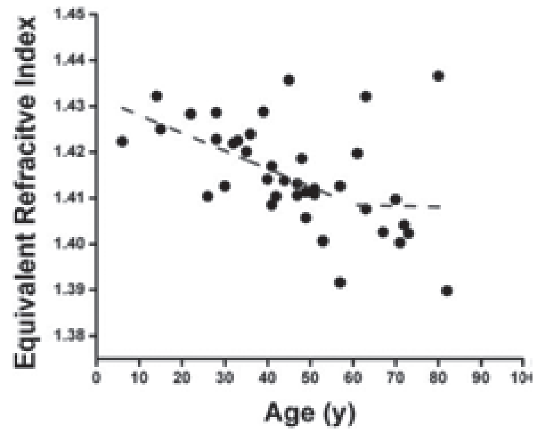

Figure 7: Refractive index X age (with permission, from Borja D, Manns F, Ho A, Ziebarth N, Rosen AM, Jain R, et al. Optical power of the isolated human crystalline lens. Invest Ophthalmol Vis Sci. 2008;49(6):2541-8)

during the evolution. Currently, this form of focus images on the retina can still be found in some fish[14], and is coupled to an engine with antero-posterior movement of the lens, within a rudimentary vitreous.

In lower vertebrates, the lens has the primary function of emmetropization, since these animals do not need to develop to near vision. They use other senses (hearing, taste, olfaction and thermal sensitivity) for the identification of objects close to eyes and locomotion in confined spaces. After all, what is the benefit of a high definition vision of the fish in dark waters? In contrast, only the higher primates develop high-definition vision for near and distance[14-16].

Therefore, it can be stated that the accommodation appeared in lower animals, during evolution, to behold the emmetropization. Thus, comparing the original idea of Helmholtz, the lens would have the secondary function in accommodation and viewing objects close to the higher primates (including humans); primarily, the lens would be closely linked to emmetropization (similarly to that observed in lower animals).

The study of emmetropization provides two ways to focus the image on the retina by the mechanism of accommodation: (i) thickening of the lens and increasing convergence of the rays entering the eye (Classical Theory of Helmholtz); (ii) elongation and increased ocular focal length lens (Figure 5). Von Helmholtz[3] was based only on the first to formulate his theory.

A new approach

In summary, the complex mechanism of accommodation has been extensively studied, but no existing theory can explain it convincingly, based on imaging tests developed in recent decades. It was also reminded that whatever the theory to explain the phenomenon of eye accommodation, will be required to explain it based on complex accommodative apparatus detected in these tests, formulate a logic that also explain the onset of presbyopia and the loss of accommodation with age.

Helmholtz relied, to formulate his theory, in purely anatomical data with what was possible for his time. Fincham[17], in 1937, based on anatomical and physiological data also tried to convince everyone (and mistakenly) that the thesis Helmholtz was possible, rather than the Tscherning theory[8], which also was based on anatomical and physiological data (but much nearer to the current reality). Koretz et al.[9,11], with data from more recent imaging studies, formulated a theory similar to Tscherning, observing the possible action of the vitreous on lens, during the accommodation process.

Koretz et al.[9], in 1986, pointed out a fact difficult to explain by the Theory of Helmholtz: the "paradox of the lens ", corroborated later by Brown et al.[10]. According to both, the only way to change the curved lens (a fact widely noted in the aging of the eye) without changing the power of convergence of the eye, occur by the simultaneous reduction of compensatory refractive index of the lens. However, Figure 7 shows that this index practically does not vary with age. Possibly even this index increases progressively after 40 years, following the gradual increase in the concentration of proteins inside the lens[18]. Therefore we can consider that the solution to the riddle of accommodation and presbyopia cannot be in the crystalline.

In higher primates, the mechanism for viewing near objects is complex[14-16]. There is no marked displacement of the lens inside the vitreous cavity. The main change is moving in the ocular posterior pole. The changes are more marked in the early stages of the life of these primates and are closely linked to greater elasticity of the ocular tissues and growth of the eyeball (emmetropization), in this stage of life. The high degree of development of the retina of primates, especially in the macular area, provided a high capacity for near vision (33 cm) for these animals (including *Homo sapiens*) and an additional manual skill. Furthermore, the development of the fovea, after the first year of human life, provides a color vision and stereoscopic high definition.

This high visual capacity was extremely advantageous for primates in the evolution of species and conquest of the environment; allowed a greater care of offspring by their parents, extending the childhood and maturation of tissues, especially the nervous system. Humans have become smarter and spread across five continents. In the study of human ocular embryogenesis, we can observe the likelihood between ontogenesis and phylogenesis: the lens appears early in embryonic divisions (3rd week of gestation). Macula and retina develops from the second half of pregnancy (20 weeks). The fovea, in contrast, only reaches its full development 1 year after birth[15,16].

Ophthalmic literature data show that for accommodation in near vision is needed to increase 1 mm in length of the vitreous cavity, which in optical terms, would correspond to an increase in lens focal length equal to 3 diopters. This value can be achieved by increasing the pressure in the vitreous cavity, which would shift the lens forward or push back the posterior pole.

If we analyze these data, we have sufficient evidence to formulate a theory to explain this complicated puzzle. Thus, the eyes of primates identify an object at a short distance (close) and, through the orderly contraction of the ciliary muscle, raises the pressure in the vitreous cavity, moving the lens forward or pushing back the posterior pole (increasing the lens focal length and focus on the retina). These changes in the posterior pole are supplemented with the thinning of subfoveal tissue in variable degree, a fine adjustment modulated by feedback system, which operates to increase or enhance the luminance contrast of the image".

The presbyopia

A point of great controversy in Helmholtz's theory was the explanation for the onset of presbyopia, universal and unavoidable fact in humans (around 40 years). According to Helmholtz, in this age group, there is an aging of the tissues surrounding the iris and lens and a progressive loss of elasticity of the lens capsule lens and the ability of ciliary muscle contraction[3]. However, these changes were never confirmed[5,10]. The most found in studies of literature, in relation to the aging eye, is the progressive hardening of the sclera[13,18]. This fact seems to us highly suggestive to justify a new approach in the etiology of presbyopia, by directing it to the posterior pole of the eye.

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