Presbyopia correction and accommodative intraocular lenses

S.A. Koopmans
Department of Ophthalmology, University Medical Center Groningen,
University of Groningen, P.O.Box 30001, 9700 RB Groningen, The Netherlands
E: s.a.koopmans@ohk.umcg.nl

A.C. Kooijman
Laboratory of Experimental Ophthalmology and Department of
Ophtalmology, University Medical Center Groningen, University of Groningen,
P.O. Box 30001, 9700 RB Groningen, The Netherlands
E: a.c.kooijman@ohk.umcg.nl

S.A. Koopmans, A.C. Kooijman, Presbyopia correction and accommodative intraocular lenses. Gerontechnology 2006; 5(4):222-230. With ageing, the ability of the eyes to focus near objects is gradually lost. The progression of this loss generally goes unnoticed until near tasks such as reading become impossible at the age of 45-50 years, called presbyopia. Usually, presbyopia is corrected with reading glasses. When a presbyopic person needs lens surgery, for instance to remove an opacified lens, the opportunity occurs to implant a lens that restores the ability to clearly see at all distances. This article discusses several methods for presbyopia correction, including multifocal and accommodative lenses.

Keywords: lens, eye surgery, accommodation, presbyopia

Accommodation is the ability to change the optical power of the eye for near vision, allowing dynamic focusing of the images of close as well as far-away objects on the retina. Credit for explaining the mechanism of accommodation in the human eye is usually given to Anthony Cramer[1], a physiologist from Groningen, the Netherlands, and Hermann von Helmholtz[2] from Berlin, Germany. Accommodation begins with contraction of the ciliary muscle located behind the iris (*Figure 1*). Contraction of the ciliary muscle moves the apex of the ciliary body inwards. This releases the circumferential tension on the zonular fibres. The zonular fibres are very fine fibres from which the lens is suspended. The elasticity of the lens capsule and the malleability of the lens contents enable the lens curvatures to increase and this results in an increase of the optical power of the lens. During relaxation of accommodation the tension on the zonular fibres increases again, thus pulling the lens back in its unaccommodated, flattened state.

PRESBYOPIA

During life, the accommodative amplitude gradually decreases. This results in difficulties with near vision at approximately 45 years of age, called presbyopia. At the age of 60 years, the accommodative amplitude has decreased to zero and all near visual tasks, which require a good visual acuity, have become impossible without the help of reading aids. Only short-sighted people (-1,5 to -3 diopter of myopia) are able to clearly see nearby without refractive correction. The decrease in accommodative amplitude affects every human being, although there are small differences in the age of onset of presbyopia. Factors that are responsible for presbyopia are lens hardening[3,4], aging of the ciliary muscle[5] and growth of the lens, resulting in geo-

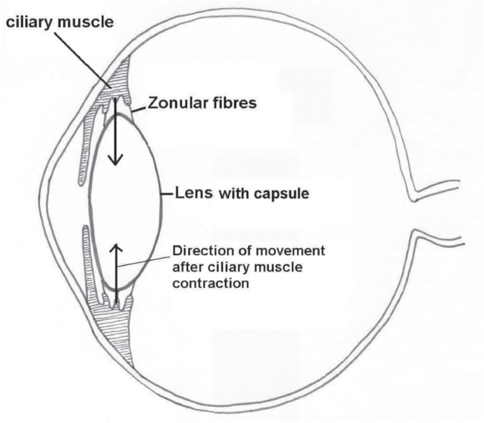

Figure 1. Schematic, transverse section of a human eyeball, showing the structures involved in accommodation

metric changes during ageing[6]. Which of these factors is most important is still the subject of scientific debate.

Glasses and monovision

There are several ways to improve near vision after the onset of presbyopia. Reading glasses are most commonly used (since about 1300). Reading glasses are plus-powered lenses which compensate for the inability of the presbyopic eye to increase the lens power. Bifocal glasses[7] consist of two parts. There is an upper part, which corrects the eye for distance vision, and in the lower part a more plus powered lens corrects for near vision. In trifocal glasses an additional lens is added between the upper and the lower part of bifocal glasses to give clear vision at an intermediate distance. In multifocal glasses, the optical power gradually increases from the upper part to the lower part of the glasses. This enables clear vision from far away to nearby and at all intermediate distances. A drawback of multifocal glasses is that distortion of the image may occur.

Developments in manufacturing techniques have made the wearing of eyeglasses, including bi- or multifocal glasses, comfortable. Eyeglasses nowadays are made of lightweight, thin and strong materials that are resistant to scratching. Strong, non-corrosive and hypoallergenic materials are used for the frames. Nevertheless, efforts to eliminate the necessity of wearing glasses[8] have never abated. After all, eyeglasses have a number of disadvantages. For one thing, they are considered to be cosmetically unattractive by some. In order to clearly see objects at varying distances, the wearer has to look through different sections of his or her bifocal or multifocal glasses. Glasses will cloud over when moving from a cold to a warm environment. People may be unable to find their glasses unless they are worn continuously. The reading addition in bifocal or multifocal glasses is usually located in the lower section of the glass, which makes it cumbersome to view close or overhead objects.

A second possibility for presbyopia correction is monovision. Monovision means that the person uses far vision correction for one eye while the other eye is corrected for near vision. This can be achieved with glasses, contact lenses, corneal laser surgery (LASIK), or by implantation of intraocular lenses after lens surgery. Despite a certain degree of success, not everyone is ready to accept this way of achieving simultaneous far and near vision. Difficulties in the brain with fusion of the images from either eye causing a reduced stereoscopic vision have been suggested as factors influencing the acceptance of monovision[9].

Multifocal lenses

A third approach to improve near vision after the onset of presbyopia is to increase the depth of field of the eye by providing it with a multifocal lens. Multifocal lenses can be provided as contact lenses or by implantation of an intraocular multifocal lens. A multifocal lens results in more than one focal point because incoming light rays are refracted differently. Usually, multifocal lenses have one focal point for distance vision and the other for nearby vision. A drawback of multifocal lenses is that the incoming light in the eye is separated in two focal points which results in a reduction of the contrast of each image. Few people wear multifocal contact lenses[10]. This could be due to age-related changes in the ocular tear film, which may affect the comfort of wearing contact lenses. Also, the fine motor skills necessary for insertion and removal of contact lenses may be an obstacle for elderly people. Multifocal intraocular lenses may cause unwanted side effects, such as glare and seeing halo's around light sources[11].

Multifocal intraocular lenses can be placed in the eye after removal of the natural lens during cataract surgery. In 2005, approximately 140,000 cataract surgeries were performed in the Netherlands (population about 16.5 million). Surgeons have the choice between implantation of a multifocal or monofocal intraocular lens. Most surgeons implant monofocal lenses and prescribe reading glasses after surgery.

ACCOMMODATIVE INTRAOCULAR LENSES

Because of the potential disadvantages of multifocal intraocular lenses, engineers have designed intraocular lenses that change the optical power of the eye in response to contraction of the ciliary muscle. These lenses are called accommodative intraocular lenses. A prerequisite is that the ciliary muscle is still active at older age. Because it is located behind the iris, ciliary muscle activity is difficult to determine. Using MRI, Strenk et al. demonstrated[12] that the ciliary muscle shows activity at all ages after an accommodative stimulus. A similar conclusion was reached by Stachs et al.[13] on the basis of high resolution ultrasound measurements. Ciliary muscle activity may thus be used to create a change in lens power using a properly designed intraocular lens.

During cataract surgery, the opacified lens is removed through an opening in the lens capsule. The lens capsule remains in the eye and the intraocular lens is implanted in this remaining capsule. Several weeks after the cataract surgery, shrinkage of the lens capsule occurs, which results in a firm fixation of the intraocular lens in the capsule. Two types of accommodative intraocular lenses are commercially available. Both are designed to shift forward in the lens capsule in response to contraction of the ciliary body. This is possible by attaching the lens optic to plates (called the haptics) by means of a hinge. The forward shift along the optical axis results in an increase of the optical power of the eye. The engineers of the accommodative lenses claim that in response to ciliary muscle contraction, the pressure in the vitreous cavity of the eye increases, which pushes the lens optic forward due to the hinged connection of the lens optic to the lens haptic. Optical calculations reveal that an anterior movement of the intraocular lens optic of one millimeter produces approximately one dioptre of accommodation[14]. Using partial coherence interferometry, a precise measurement method, changes in the position of the accommodative intraocular lens were measured in patients, implanted with these lenses[15]. The small anterior shifts of the accommodative lens optic in response to accommodative stimuli, resulted in a power change of maximally one dioptre. However, in most patients, the power changes were less and these decreased several months after implantation of the accommodative lens[16]. Although such amounts may be of some help, a restoration of three to four dioptres of permanent accommodation is necessary to benefit all presbyopes[17].

After implantation of an accommodative lens, functional tests, such as reading performance, are also important. A comparable reading performance was reported in patients implanted with multifocal or accommodative intraocular lenses while patients implanted with standard, monofocal intraocular lenses had the lowest reading performance. In some patients the hinged connection between the lens optic and lens haptic of the accommodative intra-ocular lens resulted in an unwanted change in lens position. After shrinkage and fibrosis of the lens capsule, decentrations of the lens optic occurred[18].

In summary, the present accommodative intraocular lenses show small measurable optical power changes and an improved reading performance when compared with standard monofocal lenses, but the accommodative amplitude is variable and their fixation in the eye is less stable than that of conventional intraocular lenses. Other types of accommodative lenses such as the Sarfarazi lens or the NU-lens have been proposed. However, in view of the limited availability of peer-reviewed publications describing results of clinical or preclinical testing, these lenses will not be discussed here.

Accommodative lens refilling

Since hardening of the lens substance is considered an important factor contributing to the development of presbyopia, surgeons have considered removing the hardened lens substance through a small opening in the lens capsule and replacing the lens contents with a soft refill material in order to restore accommodation. The refilling material should be soft enough so that it can be injected in the lens capsule through the small capsular opening. In 1964, the first experiments with this kind of surgery were described[19]. Despite the early beginning of the experiments, this method for restoration of accommodation is still experimental. There are still several questions and potential problems that have to be addressed before such a technique for restoration of accommodation can be applied in humans.

In order to refill the lens, a material with suitable properties has to be used. The material must be optically clear and safe for the eye. In the past, several authors experimented with silicone materials[19-21]. Silicones are also used in regular, foldable intraocular lenses, and this material has a history of being well-tolerated when implanted in the human eye[22]. An important aspect is the refractive index of the refilling material. In the first experiments with lens refilling in 1964, a silicone material with a refractive index of 1.40 was used. The equivalent refractive index of the natural human lens is 1.42, and the refilled lenses had insufficient optical power when compared to the natural human lens. Recently, silicone materials with a refractive index of 1.42 were developed by AMO Groningen BV, a company that manufactures intraocular lenses. This new silicone material consists of two parts (A and B), which are mixed together before injection. Mixing part A and B starts a chemical cross-linking reaction, which takes several hours and results in a change of the liquid silicone into a soft gel. The silicone material can be injected in the capsular bag when it is still liquid. To prevent leaking of the refill material, a small plug was developed which closes the opening in the lens capsule[23]. Such a plug allows refilling of the lens capsule with variable amounts of material.

Another important aspect of the refilling material is its Young's modulus, which indicates the elasticity. The accommodative amplitude obtained with a refilled lens should be at least equal to that of a young natural human lens and not be limited by stiffness of the refill material. This can be tested in an ex vivo set-up in which accommodation (or rather desaccommodation) is modelled by a stretch ring[24] (*Figure 2*).

The human lens, suspended in the ciliary muscle ring from the zonular fibres, is attached to a plastic ring by sutures. The tension on the sutures is controlled with a stepper motor. The change in optical power of the lens can be measured while the tension on the sutures is increased stepwise. Lenses refilled with the softest silicone material showed optical power changes comparable to that of a 20 year old natural lens, while unoperated, presbyopic lenses did not show any lens power change. This experiment demonstrates that an accommodative change comparable to that of a 20 year old natural lens can be restored to a 60 year old presbyopic lens, when the lens is refilled with the softest silicone material.

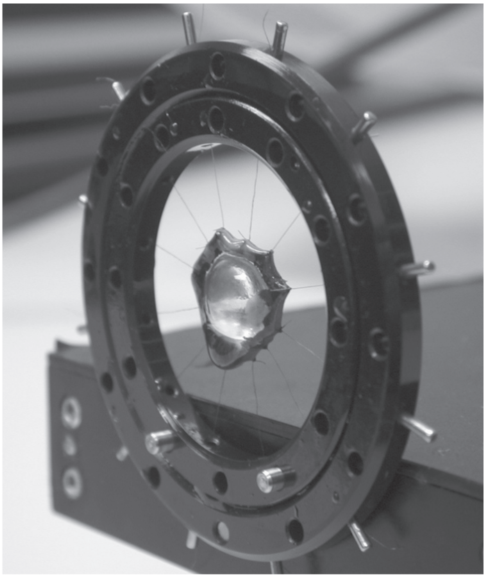

Figure 2. Stretch ring used to induce accommodative changes in human lens, zonula and ciliary body specimens; Rotation of the outer ring resulted in an increase or decrease of the tension of the sutures; The optical power of the lens has been measured along the optical axis of the lens

Before the lens capsule can be refilled with a soft silicone material, the lens contents have to be removed. This must be done through a small opening in the lens capsule, because the capsule must be kept as intact as possible. In an older, presbyopic person, lens contents are hard and may be difficult to remove. Manipulation of the lens contents with instruments through a small capsular opening can easily cause tears in the lens capsule, because the thickness of the human lens capsule is only 10 µm. Therefore, the combination of a small capsular opening with a hard, presbyopic lens makes lens removal technically challenging. Regular cataract removal techniques and instrumentation cannot be simply copied, because in regular cataract surgery the lens contents are removed through much larger openings in the lens capsule (5 mm in diameter) than those used for lens refilling (1-1.5 mm in diameter). Regular cataract removal is usually done with a hollow ultrasound needle with a diameter of 0.9 mm, surrounded by an irrigation sleeve which provides a saline solution to the eye in order to keep it pressurized. This method to remove a cataract is called phacoemulsification. The total diameter of the phacoemulsifier is approximately 1.5 mm and using this instrument to remove the human lens contents through an opening of 1.5 mm frequently results in tearing of the lens capsule. Laser phacoemulsifiers exist, but the diameter of these instruments (1.5-2.0 mm) is still too large to remove the lens contents through a capsular opening of 1-1.5 mm. Technical development will have to take place to provide an instrument which will enable surgeons to remove the human lens contents through a capsular opening of 1-1.5 mm. The lens refilling technique has been carried out successfully in various animal models and eyes of human corpses[24-25]. These animal models differ from the human clinical situation because the animals used are young and have soft lenses which can be aspirated easily. Eyes of human corpses are available without a cornea or the cornea needs to be removed because it is opaque. This makes experimental lens refilling surgery in animal models and eyes of human corpses technically easier but these models do not represent the challenges of lens removal in a human clinical situation very well. So, although lens refilling surgery can be carried out under experimental circumstances, a need for technology remains, which enables removal of a hard human lens through a small opening in the lens capsule.

Usually, after lens surgery, cells remain on the inside of the lens capsule. From regular cataract surgery, it is known that these remaining cells start to divide and transform into cells found in scar tissue. This results in a slowly progressive opacification of the lens capsule, causing a decrease in vision. This type of opacification is known as after-cataract or posterior capsular opacification. In regular lens surgery for cataract this opacification is treated with a Yag-laser. With the Yag-laser a hole is made in the opacified lens capsule, so that the optical axis of the lens becomes clear again. When the lens is filled with a soft silicone material after lens refilling surgery, it is not possible to create a hole in the opacified capsule because it will result in bulging of the silicone material through such a hole. Therefore, all cells capable of causing capsular opacification have to be removed from the inside of the lens capsule during the lens surgery. To kill all the lens cells, toxic compounds have been used[25]. They are left in the lens capsule for some time after which they are removed. A side effect of toxic compounds is that they can damage other ocular structures. Therefore they must only come into contact with the inside of the lens capsule without leaking to the rest of the eye. This can be achieved by dissolving the toxic compounds in a visco-elastic material which is regularly used in eye surgery (sodium-hyaluronate). Sodiumhyaluronate can be injected in the lens capsule without leaking to other eye structures. After some time, it can be aspirated again from the capsule. Using sodiumhyaluronate with actinomycin D (a toxic compound that interferes with DNA) on the inside of the lens capsule during lens refilling surgery, capsular opacification was effectively prevented in experiments performed with rabbits that underwent experimental lens refilling. However, more work has to be done to determine more precisely the effectiveness and safety of this treatment in other models.

When a lens refilling material is injected in the emptied capsular bag, the amount of injected refill material will determine the curvature of the anterior and posterior lens capsule and thus the optical power of the lens. In regular cataract surgery, intraocular lenses are used that are available in steps of 0.5 diopter in the range from 0 to 33 diopter. Before cataract surgery, the length of the eye and the corneal curvature are measured. Using these data, a prediction can be made of the resulting optical situation after lens implantation. A lens is chosen from a stock of lenses, based on this prediction. Usually, these predictions are very accurate; 80-90% of patients achieve the desired eye refraction within ± 0.5 diopter[26]. During lens refilling, the surgeon has to establish preoperatively, or determine intra-operatively, the amount of refilling material that must be injected in order to achieve the desired lens power. Today, no systems are available that provide feedback to the surgeon that the right amount of material is injected. In an experiment with refilling of pig lenses, Koopmans et al.[27] found that injection of 0.04 ml of refilling material increased the lens power by one diopter. This gives an indication of the precision needed with which the material is injected during lens refilling. A technical solution to measure the refraction of the eye during the lens surgery could be a system mounted on the surgical microscope, but these do not exist yet and will have to be developed.

Among primates, rhesus monkeys have been shown to have high accommodative amplitudes and an accommodative anatomy and mechanism similar to that of the human eye[28-30]. They also develop presbyopia with a relative age course similar to that of humans culminating in a near complete loss of accommodation by the age of 25 to 30 years[31]. Therefore, rhesus monkeys are a suitable animal model for studies of accommodation, presbyopia, and lens refilling experiments. In monkey accommodation studies, carbachol chloride or pilocarpine can be used to stimulate accommodation while the monkey is under general anaesthesia. These substances can be applied to the eye by iontophoresis or eye drops and they give a strong stimulus to the ciliary muscle. Accommodation can be measured with a refractometer, which measures the refractive state of the eye. A requirement for a refractometer measurement is that the lens and the rest of the optical path through the eye are clear. In the past, experiments have been described in monkeys in which the lens nucleus and cortex were removed and the capsular bag was refilled with a silicone material[32-34]. The success of these procedures as determined by the ability to measure accommodation in the eyes varied due to inflammation and the development of capsular opacification.

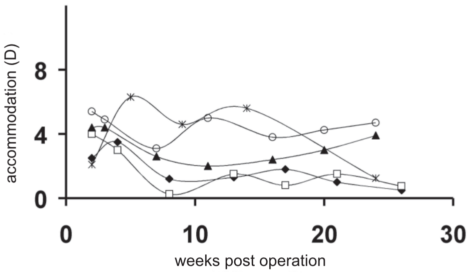

Figure 3. Accommodative amplitude in the left eye of five adolescent rhesus monkeys after lens refilling with a silicone polymer; Accommodation was stimulated with carbachol iontophoresis (□ ♦ ▲ ○), or pilocarpine eyedrops (*); Standard deviation of the accommodative amplitude varied between 0.2 and 1.2 diopter

Using a special treatment protocol to minimize postoperative inflammation and using a treatment with actinomycin D dissolved in sodiumhyaluronate in the capsular bag to prevent capsular opacification, Koopmans et al.[35] were able to measure accommodation in five adolescent refilled rhesus monkey lenses for a period of 37 weeks postoperative. After this period, capsular opacification prevented further optical measurements of accommodation and in three monkeys the accommodative amplitude had decreased to almost zero. An accommodative amplitude of maximally 6.3 diopter was measured.

Figure 3 shows the time course of the accommodative amplitude in the five monkeys. These experiments show that a certain level of accommodation can be restored after lens refilling in adolescent rhesus monkeys. Further experiments are necessary to study the accommodative amplitude in presbyopic monkeys. Also, in the future, a more permanent prevention of capsular opacification deserves further attention.

Conclusion

Summarizing the state of development of accommodative intraocular lenses, it may be concluded that the accommodative intraocular lenses which are commercially available and which shift along the optical axis of the eye offer a limited amount of accommodation. Accommodative lens refilling with a soft, transparent material may offer larger amplitudes of accommodation, but this technique is still in a developmental stage. Glasses, monovision, or multifocal lenses will remain the most important methods for presbyopia correction, despite the fact that they are compromises in terms of visual quality. Given the worldwide interest in the correction of presbyopia, the prospects for further research and development of accommodating lenses are excellent.

Acknowledgement

The research on Accommodative Lens Refilling was financially supported by Advanced Medical Optics, Groningen, The Netherlands.

References

1. Cramer A. Het Accommodatievermogen der oogen physiologisch toegelicht. Haarlem: De Erven Loosjes; 1853
2. Bericht zur Bekanntmachung geeigneten Verhandlungen der Königlichen Preussischen Akademie der Wissenschaften. Berlin: Verlag der Königliche Akademie der Wissenschaften; 1853: Februar
3. Pau H, Krantz J. The increasing sclerosis of the lens and its relevance to accommodation and presbyopia. Graefes Archive for Clinical and Experimental Ophthalmology 1991;229:294-296
4. Fisher RF. Presbyopia and the changes with age in the human crystalline lens. Journal of Physiology (London) 1973;228:765-779
5. Neider MW, Crawford K, Kaufman PL, Bito LZ. In vivo videography of the rhesus monkey accommodative apparatus. Age-related loss of ciliary muscle response to central stimulation. Archives of Ophtalmology 1990;108:69-74
6. Bito LZ, Miranda OC. Accommodation and presbyopia. In: Reinecke RD, editor. Ophthalmology Annual. New York: Raven Press 1989. pp103-128
7. Invented by Benjamin Franklin in 1780; www.college-optometrists.org/index.aspx/pcms/site.college.What_We_Do.museyeum.online_exhibitions.artgallery.bifocals; Retrieved October 18, 2006
8. Khan-Lim D, Craig JP, McGhee CJP. Defining the content of patient questionnaires: Reasons for seeking Laser in situ keratomileusis for myopia. Journal of Cataract and Refractive Surgery 2002:28(5):788-794
9. Toit R du, Ferreira JT, Nel ZJ. Visual and non-visual variables implicated in monovision wear. Optometry and Vision Science 1998;75:119-25
10. Morgan PB, Efron N. A decade of contact lens prescribing trends in the United Kingdom (1996-2005). Contact Lens Anterior Eye 2006;29:59-68
11. Lane SL, Morris M, Nordan L, Packer M, Tarantino N, Bruce Wallace III R. Multifocal Intraocular Lenses. Ophthalmology Clinics of North America 2006;19:89-105
12. Strenk SA, Semmlow JL, Strenk ML, Munoz P, Gronlund-Jacob P, DeMarco JK. Age-related changes in human ciliary muscle and lens: a magnetic resonance imaging study. Investigative Ophthalmology and Visual Science 1999;40:1162-1169
13. Stachs O, Martin H, Kirchhoff A, Stave J, Terwee T, Guthoff R. Monitoring accommodative ciliary muscle function using three-dimensional ultrasound. Graefes Archive for Clinical and Experimental Ophthalmology 2002;240:906-912
14. Ho A, Manns F, Pham T, Parel J-M. Predicting the performance of accommodating intraocular lenses using ray tracing. Journal of Cataract and Refractive Surgery 2006;32:129-136
15. Findl O, Kriechbaum K, Menapace R. Laser-interferometric assessment of pilocarpine-induced movement of an accommodating intraocular lens: a randomized trial. Ophthalmology 2004;111:1515-1521
16. Dogru M, Honda R, Omoto M, Toda I, Fujishima H, Arai H, Matsuyama M, Nishijma S, Hida Y, Yagi Y, Tsubota K. Early visual results with the 1CU accommodating intraocular lens. Journal of Cataract and Refractive Surgery 2005;31:895-902
17. Weale RA. The accommodation of lens implants. Ophthalmic Research 2005;37(3):156-158

18. Cazal J, Lavin-Dapena C, Marin J. Accommodative intraocular lens tilting. American Journal of Ophthalmology 2005;140:341-344
19. Kessler J. Experiments in refilling the lens. Archives of Ophthalmology 1964;71:412-417
20. Nishi O, Nishi K. Accommodation amplitude after lens refilling with injectable silicone by sealing the capsule with a plug in primates. Archives of Ophthalmology 1998;116:1358-1361
21. Haefliger E, Parel J-M. Accommodation of an endocapsular silicone lens (Phaco-Ersatz) in the aging rhesus monkey. Journal of Refractive Corneal Surgery 1994;10:550-555
22. Abela Formanek C, Amon M, Schild G, Schauersberger J, Kolodjaschna J, Barisani-Asenbaum T, Kruger A. Results of hydrophilic acrylic, hydrophobic acrylic, and silicone intraocular lenses in uveitic eyes with cataract: comparison to a control group. Journal of Cataract and Refractive Surgery 2002;28:1141-1152
23. Terwee T, Koopmans SA. A device for use in eye surgery. US Patent 2002/0107567A1
24. Koopmans SA, Terwee T, Barkhof J, Haitjema HJ, Kooijman AC. Polymer refilling of presbyopic human lenses in vitro restores the ability to undergo accommodative changes. Investigative Ophthalmology and Visual Science 2003;44:250-257
25. Nishi O, Nishi K, Mano C, Ichihara M, Honda T. Lens refilling with injectable silicone in rabbit eyes. Journal of Cataract and Refractive Surgery 1998;24:975-982
26. Haigis W., Lege B., Schneider B. Comparison of ultrasound biometry and partial coherence interferometry for intraocular lens calculation according to Haigis. Graefes Archive for Clinical and Experimental Ophthalmology 2000;238:765-773
27. Koopmans SA, Terwee T, Haitjema HJ, Deuring H, van Aarle S, Kooijman AC. Relation between injected volume and optical parameters in refilled isolated porcine lenses. Opthalmological and Physiological Optics 2004;24:572-579
28. Glasser A, Kaufman PL. The mechanism of accommodation in primates. Ophthalmology 1999;106:863-872
29. Rohen JW. Scanning electron microscopic studies of the zonular apparatus in human and monkeys' eyes. Investigative Ophthalmology and Visual Science 1979;18:133-144
30. Bito LZ, DeRousseau CJ, Kaufmann PL, Bito JW. Age dependent loss of accommodative amplitude in rhesus monkeys: an animal model for presbyopia. Investigative Ophthalmology and Visual Science 1982;23:23-31
31. Kaufman PL, Bito LZ, DeRousseau CJ. The development of presbyopia in primates. Transactions of the Ophthalmological Society of the United Kingdom 1982;102:323-326
32. Nishi O, Nakai Y, Yamada Y, Mitzumoto Y. Amplitudes of accommodation of primate lenses refilled with two types of inflatable endocapsular balloons. Archives of Ophthalmology 1993;111:1677-1684
33. Haefliger E, Parel J-M, Fantes F, Norton EW, Anderson DR, Forster RK, Hernandez E, Feuer WJ. Accommodation of an endocapsular silicone lens (Phaco-Ersatz) in the nonhuman primate. Ophthalmology 1987;94:471-477
34. Sakka Y, Hara T, Yamada Y, Hayashi F. Accommodation in primate eyes after implantation of refilled endocapsular balloon. American Journal of Ophthalmology 1996;121:210-212
35. Koopmans SA, Terwee T, Glasser A, Wendt M, Vilupuru A, van Kooten TG, Norrby S, Haitjema HJ, Kooijman AC. Accommodative lens refilling in rhesus monkeys. Investigative Ophthalmology and Visual Science 2006;47:2976-2984