METHOD OF PRODUCING INTRAOCULAR LENSES IN VIVO

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FIELD OF INVENTION

The present invention relates to the field of intraocular lenses (IOLs) and in particular to new lens materials as well as to methods of producing accommodating lenses based on these materials in vivo, which means that the lens is formed in the capsular bag of the eye.

BACKGROUND OF THE INVENTION

When an ophthalmic surgeon operates on a cataract (s)he replaces the defective natural lens with a small artificial lens, an IOL. In order to remove the natural, cataractous lens, as well as to prepare for the introduction of the IOL, an incision must be made into the eye. For many years most of the IOLs were made of poly(methylmethacrylate), a material with good optical characteristics and compatibility with tissues in the eye. A disadvantage of PMMA is, however, that it is a very rigid material and the incision must be made big enough, at least 5–6 mm, for implantation of the lens. With improved devices for removal of the natural lens by phacoemulsification, requiring only a rather small incision, there was a need for lenses with deformable optics. This intended property can be achieved, for instance, by making lenses which are foldable or can be dried to a reduced size, but which swells to its original shape in the eye. Various silicone or hydrogel based lenses have been suggested and in some cases also commercialized. In such small incision surgery an opening of only 3–4 mm is required.

The implantation of lenses of the types mentioned above necessitates the patient using spectacle correction for reading. More recently, to overcome this limitation of the conventional IOL, increasing attention has been given to refractive, as well as diffractive, bifocal or multifocal lenses. The use of such lenses is increasing slowly, but as they introduce an optical deficiency in patients, a reduced perception of contrast, which becomes more acute in twilight, their widespread application may be limited.

Even with the mentioned types of improved implantable IOLs, available on the market, there is still a desire to obtain a lens for which is required an even smaller incision and which behaves like the natural lens in the eye, i.e. to be accommodating, with a focal point which is regulated by action of the ciliary muscle in the eye. In order to allow for a really small incision it would be necessary to form the lens inside the eye from a solution which is injected into the capsular bag or into a balloon placed inside the bag. Lenses formed from an injected solution of monomers have already been suggested in the literature and are based on a technique in which the natural lens is removed and, after cleaning of the capsular bag, a polymerizable composition is injected into the bag, whereupon the solution is polymerized, e.g. after initiation by light of suitable wavelength, using the form of the capsular bag as the mold. Thin walled inflatable balloons of silicone rubber have also been developed which can be inserted into the capsular bag and filled with the desired polymer system.

Most researchers of the development of the accommodative re-fill lens have used silicone based systems for filling the capsular bag, either in the form of silicone oils or low temperature vulcanizing (LTV) silicone elastomers. Such

systems suffer from disadvantages in the context of re-fill lens formation: the dimethyl silicones have a restricted refractive index (1.40), LTVs cure slowly, up to 12 hours may be needed to complete their setting and their slow setting may result in material leakage out of the capsular bag through the surgical incision. In order to overcome this problem, U.S. Pat. No. 4,542,542 discloses such a silicon based injected system which is partially cured by heat in the vicinity of the injection hole of the capsular bag to effect a first sealing effect. It is a further complication that the high viscosities of some silicone oils and intermediates make their air-bubble free injection very difficult.

Hettlich et al (German J Ophthalmol (1992) 1 p. 346–349) were among the first to propose the use of photopolymerization of a monomer system as an alternative approach to setting the material within the capsular bag. He pointed to the clinical success of blue light photocurable resins for dental applications and explored the use of such systems as injectible materials for filling capsular bags. The systems used by Hettlich et al. were effective in demonstrating the efficacy of blue light photocurable resins for filling capsular bags. Another example of an injectible system is described in EP 414219, in which the liquid composition comprises a difunctional acrylate and/or methacrylate ester and a photoinitiator activatable by light of wavelength 400–500 nm. By choosing an initiator of such high wavelength the presence of a UV absorber, which is desired to be present in the final lens in order to protect the retina from damage, does not create a problem.

Unfortunately, the in vivo polymerizable systems described so far do not solve all the problems involved with this interesting and potentially very useful concept, as e.g. leakage of monomers and initiator from the bag into the surrounding parts of the eye between injection and polymerization might occur. With increasing polymerization time such leakage might be substantial and cause serious complications. Another disadvantage observed in systems of the type described above is shrinkage of the material during polymerization with the formation of a lens which does not completely fill up the capsular bag. Further, the systems used have formed materials with moduli too high to allow accommodative processes. The natural lens of the eye is a material with extremely low modulus, in the general range 1–5 kPa, which can be compared to glassy plastics with a modulus of six orders of magnitude greater. PMMA as mentioned above has a value around 3000 MPa.

It would consequently be highly desirable to be able to obtain an ophthalmically acceptable solution which could be injected into the capsular bag of the eye with a conventional cannula after the natural lens has been surgically removed and that such a solution could be subjected to a process that would result in the production of an intraocular lens capable of functionally replace the natural lens, while avoiding the above-mentioned problems. In particular, such a solution must be water based and in a simple manner capable of being reacted into a gel formed solid lens material. It has earlier been described in U.S. Pat. No. 5,665,840 how to produce contact lenses from a water soluble crosslinkable pre-polymer. The production involves a photoinitiator which is activated by UV-light to produce crosslinking reaction to the gel formed lens material. In this publication it is not considered how to inject a water based solution into the capsular bag for lens production and arrive with a lens of a suitable modulus.

It is obvious that several technical problems remain before a method of producing an intraocular lens from injecting a water based aqueous solution directly into the