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CATARACT SURGERY AND MONOFOCAL INTRAOCULAR LENSES

REFRACTIVE AND PRESBYOPIA CONSIDERATIONS

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Cataract surgery is currently the most common surgical procedure in the developed world, whereas cataract is the most common cause of treatable blindness in the developing world. During past decades, cataract surgery has evolved from a potentially traumatic intervention, bearing several and frequent complications, to a brief and safe outpatient surgery. Evolution of surgical methods from intracapsular extraction to extracapsular extraction with phacoemulsification has changed the indications for cataract surgery from severe visual loss due to cataract formation to mild visual ailment or even to correction of ametropias in presbyopic patients. At the same time, in developed countries, patients undergoing cataract surgery have high expectations for the postoperative result and want spectacle independence in distance and near vision.[1]

When their presbyopia is accompanied by incipient cataract formation, patients who seek presbyopia correction are more often guided toward cataract surgery than to corneal surgery. Even in the presence of a clear crystalline lens, if there is concomitant refractive error (eg, moderate to high hyperopia), cataract surgery, rather than corneal surgery, is the procedure of choice. Cataract surgery is then called refractive lens exchange (RLE), thus indicating that the procedure is taking place without the presence of a cataract.

Apart from the evolution in the surgical technique, new intraocular lens (IOL) materials and designs have given additional impetus to the use of cataract surgery for refractive reasons. New foldable IOLs can be easily inserted in the capsular bag through minor incisions, and modern IOL designs are now offered for presbyopia (multifocal, accommodative IOLs), astigmatism correction (toric), reduced aberrations (aspheric), and blue-light protection (tinted IOLs; Figure 17-1).

MODERN CATARACT SURGERY

Basics of Techniques

Introduction to Techniques of Cataract Surgery

Two generic terms are used for cataract extraction—intracapsular and extracapsular.

Intracapsular cataract extraction (ICCE) consists of removing the whole lens still within its intact capsule.

Pallikaris IG, Plainis S, Charman WN.
Presbyopia: Origins, Effects, and Treatment (pp. 151-160).

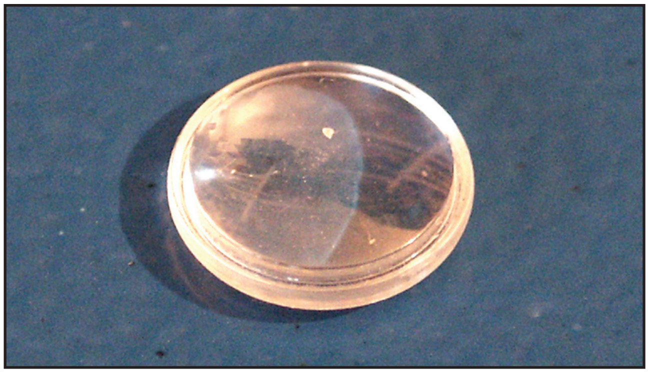

Figure 17-1. Photograph of the Ridley posterior chamber IOL (1949). (Reprinted with permission of Ioannis Pallikaris, the Pallikaris-Huber collection.)

This technique has significant intraoperative and postoperative complications, and the visual results are relatively poor. Vitreous loss, hemorrhage, retinal detachment, chronic cystoid macular edema, and high astigmatism are frequent complications. Therefore, it is now rarely used in the developed world, and only for selected cases, such as those with an extensive rupture of the zonule of Zinn.

Extracapsular cataract extraction (ECCE) consists of removing the crystalline lens while retaining the capsule within the eye. The significant advantage of this technique is that, postoperatively, the capsule remains the natural barrier between the anterior and the posterior segments of the eye. It can also host the IOL that will restore the ocular refraction. In manual extracapsular extraction, the nucleus of the lens is removed en bloc and therefore requires a relatively large incision. Extracapsular extraction gained preference among ophthalmologists after the introduction of IOLs by Dr. Harold Ridley, and, until the advent of phacoemulsification, it represented the gold standard in cataract extraction.[2] Today, it still retains a small but significant place in cataract surgery for selected cases.

Phacoemulsification

In modern cataract surgery, phacoemulsification was introduced in 1967 by Dr. Kelman, as the core part of the procedure.[2] Along with the introduction of foldable IOLs, phacoemulsification allowed surgery to be performed through a small, sutureless incision with minimal postoperative astigmatism. It involves breaking the lens nucleus into a mixture of emulsion and small fragments that can be aspirated. The procedure utilizes ultrasonic energy to fragment the lens inside the eye. This energy is delivered through a small-diameter handpiece that aspirates the emulsified nucleus and irrigates the chamber. This can be done through a small incision—initially 3.2 mm—although the latest developments allow removal through a sub-2-mm incision. The small incision offers several advantages. A small incision makes it possible to maintain excellent control of the anterior chamber volume due to the tight seal created around the handpiece and the surge control via the system software or hardware elements throughout the procedure. The surgery is performed within a closed environment, allowing more control of intraocular pressure, thus reducing the likelihood of a suprachoroidal or expulsive hemorrhage. In addition, there is less danger of vitreous prolapse if a posterior capsule tear occurs. Due to the small incision, there is less induced corneal astigmatism, more rapid visual recovery, and a more predictable refractive outcome postoperatively. The small wounds require no sutures and are thus minimally invasive to corneal biomechanics and curvature.

Phacoemulsification is less invasive, has fewer complications, and results in quicker and more stable visual rehabilitation than other techniques. The disadvantages include the use of sophisticated and costly equipment and the need for appropriate support and maintenance.[2]

The procedure begins with implementation of anesthesia, which may be general, local injection, topical, or intracameral. The method selected depends on the characteristics of the patient, the eye, and the surgeon. Topical anesthesia is gaining popularity, but proper patient selection, based on previously mentioned parameters and mainly on the ability of the patient to cooperate during surgery, is important.

Incisions are usually located at the edge of the cornea (clear corneal incisions) and are fashioned in a step-wise manner to provide self-sealing characteristics. The length of the incision is governed not only by the diameter of the phacoemulsification handpiece but also by the diameter of the IOL inserter. Modern foldable IOLs are inserted through incisions that may be less than 2 mm in length. Following the incision, a viscoelastic substance is injected into the anterior chamber of the eye to maintain the space and protect the endothelium of the cornea during the remainder of the procedure. Two major categories of viscoelastics are currently available—the cohesive, which are mainly used to maintain the space, and the dispersive, which are used to isolate areas and protect the endothelium. The proper use of these agents in phacoemulsification procedures has made it possible to perform surgery in a more controlled environment, causing minimal trauma to the corneal endothelium.

The next step in the procedure is the anterior capsulotomy, which consists of the contoured removal of the anterior part of the anterior capsule so to proceed with the lens fragmentation and removal while preserving the lens capsule at the same time. The method, shape, and dimensions of the anterior capsulotomy depend on the surgeon, the characteristics of the cataract, and the IOL that will be inserted. Following capsulotomy, cleavage of the lens cortex from the capsule is performed by means of hydrodissection. In addition, separation of the nucleus from the epinucleus by fluid injection (hydrodelineation) may also be performed. The ideal end point of the hydrodissection process is to achieve a free rotation of the nucleus within the cortical and epinuclear bed. The lens material can then be manipulated while performing phacoemulsification. Several methods for the manipulation of the lens during fragmentation can be used, all involving the combined application of ultrasound and mechanical forces to the lens and cortex. One of the most popular initial methods is the “divide and conquer” technique, which includes breaking the nucleus into quadratic sections. Subsequently, various chopping techniques have gained popularity. After the nucleus is removed, the remaining cortical and epinuclear material is aspirated. Once the lens capsule is empty, a viscoelastic substance is reinjected into it to maintain the space, and the foldable replacement lens implant is put into the capsule. After removing the viscoelastic material, the surgeon carefully checks the incision to ensure that it is watertight. A suture is rarely needed.

Complications of Cataract Surgery

The most frequent postoperative complication of modern cataract surgery is posterior capsule opacification (PCO). It significantly decreases patients' visual acuity and, in most cases, requires treatment by laser posterior capsulotomy.[3] It is believed that this complication is due to residual or regenerated lens epithelial cells or fibers that migrate centrally and reduce the transparency of the posterior capsule. Careful removal of cortical material (“capsular polishing”) and newer IOL designs, having a square edge to the optic, are associated with a lower incidence of PCO due to reduced migration of remnant cells.

Anterior capsule contraction is a rare complication that occurs more often when the anterior capsulotomy is small. It leads to reduction of visual acuity due to IOL decentration or by direct involvement with the visual axis.

Corneal decompensation is a potentially severe complication of phacoemulsification that occurs due to endothelial cell damage during surgery. Such damage can be a result of direct trauma during surgery, ultrasound energy, or even the toxic effect of the pharmacological agents used. A small percentage of endothelial cells are always expected to be lost during phacoemulsification, but if preoperative cell density is low or surgery is more traumatic to the endothelium than expected, the possibility for endothelial decompensation increases.

One of the most severe complications of cataract surgery is postoperative infectious endopthalmitis.[4] The decreased time needed for surgery completion and the small incisions associated with phacoemulsification reduce the risk of endophthalmitis. Despite this, however, the risk after cataract surgery is reported to be between 0.1% and 0.4%. The use of intracameral cefuroxime as a prophylaxis has been reported to decrease this risk.

Retinal detachment is an additional vision-threatening complication of phacoemulsification, occurring in 1.1% of patients. Posterior capsular tear and vitreous loss, lattice degeneration, and severe myopia are risk factors for this complication.

Although cystoid macular edema (CME) is a relatively frequent complication, clinically significant macular edema (ie, that affecting vision) is rather rare.[5] Intraoperative risk factors for the occurrence of CME include vitreous traction, breakdown of the blood-aqueous and blood-retinal barriers, and intraocular inflammation via prostaglandins. Prophylactic postoperative treatment with nonsteroidal, anti-inflammatory agents is considered to reduce the risk for this complication.

A universal complication of cataract surgery with monofocal IOL implantation is the introduction of acquired presbyopia because the normal accommodation of the crystalline lens is not restored with the lens implants. In cases of monofocal IOL implantation, the ability of implanted patients for concomitant satisfactory unaided far and near vision after cataract surgery (which is called apparent accommodation and will be analyzed in the “Apparent [Pseudo-] Accommodation” section on page 158 of this chapter) is similar to that of nonoperated presbyopic phakic patients >60 years.

Femtosecond Laser-Assisted Cataract Surgery

Photodisruption, by means of a femtosecond infrared laser system, has been utilized recently for various applications in corneal surgery with significant success. Currently, there are 3 femtosecond laser systems under trial for cataract surgery. According to the initial results, it is possible to perform corneal incisions, anterior capsulotomy, and lens fragmentation, and to subsequently remove the lens material, with less or no use of phacoemulsification. The aim of this technology is to increase precision and reduce the duration and possible complications of cataract surgery by minimizing the manual aspect of the operation and the ultrasound energy needed.[6]

MODERN INTRAOCULAR LENS DESIGN

Principles

IOLs were introduced into cataract surgery in the early 50s and, after some initial disappointments, significantly improved the outcome of the operation. Since the first appearance of IOLs, there has been steady progress in materials and designs in terms of biocompatibility, feasibility of insertion, and refractive outcome. In addition to the development of presbyopic IOLs (multifocal, accommodative), the most recent advances that are incorporated in several popular monofocal designs are aspheric configurations to minimize aberrations, toric configurations for the correction of astigmatism, and the use of yellow tints to maximize retinal protection from short-wavelength radiation. Other designs that have recently been introduced include microincision IOLs that can be inserted through an incision of 2 mm or less and IOLs that provide the opportunity for correction of postoperative refractive error, such as light-adjustable lenses (see below and Chapter 20) and multi-component IOLs (see below and Chapter 18).

Intraocular Lens Materials and Biocompatibility

Most currently available IOLs are manufactured in 2 main categories of biomaterials: silicones and acrylic polymers. Acrylics are further divided into rigid (eg, poly[methyl methacrylate] [PMMA]) and foldable, either hydrophobic or hydrophilic. Each material has different properties, such as refractive index, glass transition temperature (above this temperature, the polymer exhibits flexible properties and remains rigid below this temperature), water content, mechanical properties, etc. The process of IOL manufacturing includes procedures that modify the original properties of the material, such as surface coating and incorporation of chromophores.

Several studies performed in the past few years show that the biocompatibility of an IOL depends mainly on the reaction of the lens capsule and the uvea (uveal and capsule biocompatibility) to the implanted IOL.[7] Uveal biocompatibility is related to the blood-aqueous barrier disruption due to surgery, which results in the release of proteins into the anterior chamber and absorption of these proteins by the IOL. Subsequently, there is cellular reaction and inflammatory cell deposition onto the lens surface. Studies on most modern IOLs show no clinically significant occurrence of this phenomenon. Capsule biocompatibility refers to the posterior capsule opacification, anterior capsule contraction, intralenticular opacification in piggy-back IOLs, and lens epithelial cell ingrowth. All of these complications are due to lens epithelial cell proliferation and migration.

Posterior capsule opacification is the most frequent postoperative complication of cataract surgery. It has been shown that the most important aspect for the prevention of this complication is the square-edge configuration of the optic of the IOL, although minor differences between different IOL materials exist. When it occurs, most cases of PCO can easily be treated with YAG laser capsulotomy—an easy and safe procedure. This restores a clear optical path. Another aspect of IOL biocompatibility has to do with the long-term potential for IOL optic calcification. This rare complication has been observed in several IOL materials, and it is not clear which factors predispose to its occurrence.

Intraocular Lens Optic Configuration

Aspheric Intraocular Lenses

Until recently, IOLs had spherical surfaces, resulting in the introduction of positive spherical aberration. Taking into account the positive spherical aberration of the cornea, it was suggested that this would result in a significant reduction in quality of vision in comparison with the healthy natural eye where corneal spherical aberration is partially compensated by the crystalline lens, especially in younger age groups. During the normal growth process, the crystalline lens' spherical aberration trends toward positive values, resulting in a total increase in positive spherical aberration. Aspheric IOLs have been introduced to reduce spherical aberration and to improve quality of vision.[8]

Several studies have compared the performance of patients implanted with spherical versus aspheric IOLs.[8] The major advantage of aspheric IOLs is the significant reduction of ocular aberrations, which results in better contrast sensitivity. Longitudinal spherical aberration increases as the square of the pupil radius; therefore, these differences become more significant under low lighting conditions.

The main potential disadvantage of these IOLs is that the decrease in spherical aberration results in a decrease in depth of focus (DOF), thus reducing tolerance to defocus and near acuity. It is theorized that a small amount of spherical aberration is favorable for the near vision of patients and does not significantly compromise visual quality, whereas reducing aberrations provides a single, solid focal point with blurred vision under even slight amounts of defocus. However, comparative studies of aspheric versus spherical IOLs show there is no compromise of DOF, especially in older individuals. This is because the larger DOF in the older eye depends mainly on the small pupil size rather than the optical aberrations.

The choice of IOL, from the point of view of spherical aberration, depends on the patient's characteristics, with most surgeons aiming to leave a small amount of residual positive spherical aberration rather than zero.

Toric Intraocular Lenses

Toric IOLs have been introduced for the correction of astigmatism during cataract surgery as an alternative to relaxing incisions.[9] In the past, intraoperative application of limbal or corneal relaxing incisions was the only option for the correction of large amounts of corneal astigmatism. Significant drawbacks of these techniques are their low predictability and stability and the potential complications, such as perforation. Toric IOLs have been shown to have excellent predictability and stability, thus addressing the need of patients for a flawless refractive result after surgery. The calculation of the power of astigmatism in the IOL depends on the patient's corneal astigmatism and the expected surgically induced astigmatism due to the incisions. The insertion of a toric IOL is a more sophisticated procedure, as there is a need for accurate axis alignment to achieve astigmatism correction. Misalignment of 1 degree results in a 3.3% reduction in correction of astigmatism. The main drawback of these IOLs is possible postoperative rotation, which could lead to astigmatism recurrence, although modern toric IOLs show excellent postoperative stability.

Tinted Intraocular Lenses

Until recently, most IOLs were designed to provide protection to the retina only by attenuating ultraviolet (UV) radiation while they were transparent in the visible spectrum. In the past few years, several IOLs have been manufactured that incorporate a yellow filter. This is intended to mimic the spectral absorption properties of the natural crystalline lens and consequently reduces the amount of blue (short wavelength) light reaching the retina.

Blue radiation is more likely to cause photo-oxidative damage at lower thresholds in the retina due to the higher photon energy at shorter wavelengths, which is considered as being primarily responsible for light damage to the retina. Normally, the crystalline lens offers protection to the retina from short-wavelength radiation by absorbing all of the UV-A radiation as well as a fraction of blue radiation that increases with age. Lens extraction and implantation of a clear IOL eliminates the blue-light filtering properties of the crystalline lens and presumably increases the danger of light-induced retinal damage. Due to speculations concerning the possible pathogenetic role of short wavelengths, the use of tinted IOLs in cataract surgery is expanding.

Several studies have been conducted to test the possible adverse effects of blue-light filtering by tinted lenses, mainly on color perception.[10] Recent studies have demonstrated that patients implanted with the AcrySof Natural (Alcon Laboratories, Fort Worth, TX; Figure 17-2) show normal color perception.[11-13] This normal color perception could be attributed to color-adaptation mechanisms (see Chapter 10). In vitro studies have shown that the blue-light attenuation of tinted IOLs is comparable to that of the aged crystalline lens.[14] An in vivo study of blue-light luminance perception showed that the attenuation of blue-light luminance by tinted IOLs was the same as that produced by the aging crystalline lens and was significantly greater than that of nontinted IOLs.[15]

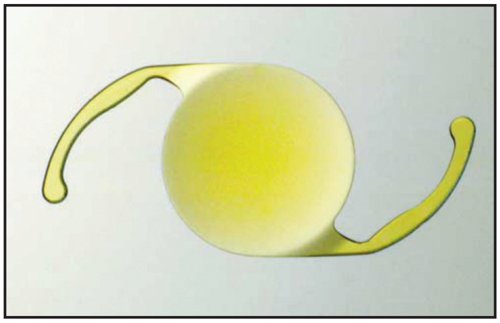

Figure 17-2. The AcrySof Natural IOL (model SN60AT) has a single-piece design with a 6.0-mm optic (right). (Reprinted from *J Cataract Refract Surg,* 30, Ernest PH, Light-transmission-spectrum comparison of foldable intraocular lenses, pp 1755-1758, Copyright 2004, with permission from Elsevier.)

Postinsertion Optically Adjustable Intraocular Lenses: Light Adjustable and Multicomponent

The pursuit of the optimum refractive result has given birth to 2 IOL designs that offer the opportunity for postoperative correction of so-called “refractive surprises” after IOL implantation.

Light-adjustable lenses (LALs, see Chapter 20) are made from a special material consisting of a polymer matrix and a macromer that is shed into the matrix. Several weeks after cataract surgery, the IOL can be illuminated with a special device delivering UV radiation to the IOL with a specific spatial pattern calculated on the basis of the residual refractive error to be corrected. Depending on the pattern, there is induction of polymerization of the macromers in a part of the IOL and a diffusion of macromers from the untreated part of the IOL to the treated part with the polymerized macromers. This results in a change in the total refractive power of the lens, which is subsequently “locked” by a second UV irradiation of the IOL in a separate procedure after 1 day.

The multicomponent IOL consists of 2 parts—a posterior part that is well set in the bag and an anterior part of the optic that is locked on the posterior part and is interchangeable to alter the IOL’s power. This requires a second intraocular procedure much less laborious than IOL exchange or piggy-back IOL insertion.

Microincision Intraocular Lenses

Microincision cataract surgery (MICS) is defined as surgery performed through incisions of less than 2.0 mm, and it aims to reduce surgical trauma and surgically-induced astigmatism (SIA).[16] The main theoretical advantages of MICS include a decrease in SIA and a reduction in the surgical aggressiveness with the comprehensive use of energy and fluidics involved in the process of lens removal. Improvement of visual outcome and high patient satisfaction are among the other advantages of this technique. Currently, there are several commercially available IOLs that can be inserted through an incision less than 2 mm. The main considerations in the manufacturing of these lenses are the ability to be folded without suffering permanent deformation, the biocompatibility (both uveal and capsular biocompatibility), the postinsertion stability, and the optical performance. Studies suggest that in vivo-available microincision IOLs perform similarly to conventional IOLs.[16] These results, therefore, support the trend toward MICS, although some studies report that incisions less than 2 mm provide no added benefit with respect to astigmatism.

Conclusions

Modern IOL designs offer excellent biocompatibility and optical performance. The optical configurations of modern lenses provide solutions for effective correction of astigmatism and for custom selection of residual spherical aberration after surgery. Also, retinal protection can be taken into account, especially for patients with high life expectancy after surgery. All of these features indicate that IOL insertion in patients of early presbyopic age (around 45 years old and above) may be acceptable for the correction of their refractive error and presbyopia, even in the absence of cataract.

REFRACTIVE CONSIDERATIONS AND CATARACT SURGERY

Intraocular Lens Power Calculation

Principles

The calculation of the required refractive power for the IOL is an essential step in the preoperative evaluation of patients undergoing surgery.[17] Algorithms, using the eye metrics that allow the refractive power of the IOL to be accurately calculated to provide the postoperative refractive result the patient wishes for, are currently under continuous development. The main parameters needed for calculation of the IOL are the corneal refractive power (curvature), the axial length of the eye, and the anterior chamber depth that corresponds to the IOL position in the eye. The calculation is more complicated in patients who have undergone previous corneal refractive surgery because the corneal refractive power cannot be calculated with the same parameters as in a nonoperated cornea. Instruments that provide the axial distances needed for IOL power calculations (biometry) are divided into 2 categories based on the principle of their function—ultrasound biometry and optical coherence biometry.

Ultrasound Biometry

Ultrasound biometry uses an A-scan probe that can be applied either in direct contact to the cornea (contact biometry) or through a fluid coupling medium (immersion biometry). Ultrasound, emitted by the probe, is propagated through the eye, and part of it is reflected whenever it encounters an interface of materials. The reflected ultrasound is used to calculate the distance between each interface using the measured time delays of the reflections and an assumed ultrasound velocity. In contact biometry, an error is introduced by the indentation caused by the probe touching the cornea. This error can be compensated for by a constant, but the constant may vary with the user. Immersion biometry is more accurate because the probe is not in direct contact with the cornea but is immersed in fluid that fills a scleral shell fitted on the globe. The main disadvantage of ultrasound biometry is the relatively low axial resolution (approximately 0.2 mm) of ultrasound waves for the measurement of small distances, such as in the human eye. Existing devices, however, perform with remarkable accuracy in everyday clinical practice.

Optical Biometry

Optical biometry uses a partial coherence laser interferometer to measure the distances between each ocular structure. The time delay and intensity of infrared light reflected back from media interfaces are measured to determine the distance from the cornea to the retinal pigment epithelium. Distances are calculated from the measured time delays by using an assumed refractive index for the eye media. This method has the advantage of being noncontact, and it also has increased accuracy in comparison to ultrasound due to its better axial resolution (approximately 0.01 mm). Drawbacks of this technology are that a relatively clear optical path is needed and the patient must have the ability to retain fixation. Thus, patients with dense opacities, such as posterior subcapsular cataract, may be unable to be measured with optical biometry.

Intraocular Lens Power Calculation Formulae

Several generations of formulae have been developed for the accurate prediction of IOL power to reach the desirable postoperative refractive result. More advanced formulae have recently been developed, involving more variables such as white-to-white and lens thickness.[17]

Management of Astigmatism During Cataract Surgery

A significant refractive consideration in modern cataract surgery is management of astigmatism.[9] One of the goals of modern cataract surgery is the correction of preoperative astigmatism. The induction of clinically significant astigmatism during surgery is considered to have been minimized by the small incisions that are utilized. Several approaches are available for the correction of astigmatism at the time of cataract surgery. They include incision placement on the steep axis of the cornea, peripheral corneal relaxing incisions (PCRIs), and toric IOL implantation. A general rule of thumb utilized by many surgeons is that for astigmatism less than 1.00 D, placement of the incision in the steep axis is enough; for astigmatism between 1.00 and 1.50 D, relaxing incisions may be necessary; and for more than 1.50 D, a toric IOL implantation should be considered. Incisions of 3.2 mm induce approximately 0.50 D of astigmatism in the axis perpendicular to the incision. When smaller incisions are used, induced astigmatism is expected to be less, although some studies suggest that the difference for incisions less than 2 mm may not be significant. Peripheral relaxing incisions are preferably used for astigmatism between 1.00 and 1.50 D because toric IOLs are more predictable and safe for larger amounts of astigmatism. The relaxing incisions are placed in the periphery of the cornea and their length is defined by nomograms that are based on the amount of the astigmatism.[9] Toric IOLs are generally preferred for more than 1.50 D of astigmatism. It is very important that the implantation is on the correct axis.

EVOLVING INDICATIONS FOR CATARACT SURGERY

The evolution in cataract surgery techniques has led to a significant reduction of complications and a significant increase in safety, efficacy, and patient satisfaction. As a result, indications for cataract surgery have changed from dense cataracts toward mild cataracts and refractive errors.

Refractive lens exchange is gaining increasing popularity for the correction of refractive errors that are outside the limits of laser correction, especially in patients of presbyopic age. Studies have shown that correction of mild and high hyperopia is more effective and stable with lens surgery than with laser surgery.[18] In addition, it is preferable to correct high myopia with lens surgery rather than corneal surgery due to the need to remove large amounts of corneal tissue and to introduce a significant change in corneal curvature if the latter is employed. In all cases, the risk of sight-threatening complications is similar, except for the risk for rhegmatogenous retinal detachment (RRD), which is increased in extremely myopic eyes. The cumulative risk for RRD in operated eyes is reported to increase as much as 10-fold in comparison to nonoperated eyes in published literature.[19] All of these potential complications have to be carefully evaluated by the surgeon and the patient before proceeding to surgery.

The evolution in IOL power calculation techniques has also played a significant role in establishing cataract surgery as a refractive rather than purely a rehabilitating procedure. New accurate instrumentation and formulae have increased efficacy in ocular axial lengths of less than 22 mm and more than 24.5 mm, as in high myopia and hyperopia. Currently, there are also formulae that are considered to be accurate in eyes that have undergone corneal refractive surgery. In such cases, one of the main parameters used for calculation—corneal power—has been altered by the refractive surgery, thus reducing the predictability of the refractive result after cataract surgery. At the same time, due to the reduced predictability of post-refractive surgery IOL power calculation, refractive lens exchange is considered a better choice than laser corneal surgery for the correction of all refractive errors in presbyopic patients, as a large percentage of these patients is expected to need cataract surgery due to clinically significant cataract in the future.

NEAR VISION AND PRESBYOPIA CORRECTION WITH MONOFOCAL INTRAOCULAR LENSES

Apparent (Pseudo-) Accommodation

Although the refractive results of cataract surgery with monofocal IOL implantation are excellent, the simultaneous restoration of unaided far and near vision is not as effective. This normally results in a need for near spectacles after cataract surgery, although satisfactory unaided far vision is achieved. However, some patients do achieve spectacle independence in their everyday activities.[20] This phenomenon has been characterized as apparent accommodation, or pseudoaccommodation. It has been attributed to several factors: small pupil size and increased total and corneal aberrations, which may extend DOF; the amount and axis of astigmatism; and axial movement of the IOL.[21]

Depth of focus is an essential characteristic of all optical systems and is mainly dependent on aberrations and pupil size (see Chapter 3). The amount of apparent accommodation is highly correlated to the calculated DOF in eyes implanted with monofocal IOLs. On the other hand, DOF is negatively correlated to normal visual acuity—the higher the visual acuity, the lower the DOF. Spherical aberration is a significant contributor to increased DOF in the normal human eye. As noted previously, aspheric IOL implantation is intended to decrease total spherical aberration to achieve optimal in-focus visual acuity and contrast sensitivity. Some studies of near visual acuity in patients with aspheric versus spherical IOLs report controversial results. In some studies, patients with aspheric IOLs have lower DOF and, as a result, have reduced distance-corrected intermediate and near visual acuity in comparison to patients with spherical IOLs. In contrast, there are studies that show no difference in pseudoaccommodation between patients with aspheric and spherical IOLs, as the diameter of out-of-focus blur circles is proportional to the pupil diameter.[22-24]

One of the most significant contributing factors to apparent accommodation seems to be against-the-rule astigmatism. When compared with with-the-rule astigmatism, against-the-rule offers better near visual acuity, whereas the unaided far vision is equally affected. It has been calculated that a moderate myopic astigmatism of -1.50 D x 90 degrees can often offer pseudophakic patients a rewarding independence from spectacles, both for distance and near vision. In a study comparing a group of patients with good distance and near visual acuity (ie, having substantial pseudoaccommodation) with a control group (both groups being implanted with monofocal IOLs), several parameters were evaluated, and the existence of against-the-rule astigmatism was the only demonstrable statistically significant difference between groups. It is speculated that astigmatism contributes to increased DOF, but it may also improve near visual acuity due to the fact that the Latin alphabet has a significant vertical component, thus making it more easily read by patients having against-the-rule astigmatism (ie, having the vertical focal line on the retina during near vision).

Axial movement of the IOL during accommodative effort may also contribute to pseudoaccommodation. This constitutes a dynamic component of the phenomenon, in contrast to the static nature of the other components (ie, DOF, astigmatism, etc). This component of pseudoaccommodation is called *pseudophakic accommodation*, whereas the static component is called *pseudophakic pseudoaccommodation*.

According to published equations, pseudophakic accommodation depends on 4 parameters: the range of movement of the IOL, the position of the IOL, the keratometric values, and the axial length (AL). It has been calculated that accommodation, obtained per 1.0 mm of forward IOL movement, varies with AL from 0.80 D in a long eye to 2.30 D in a short eye.[25]

Several in vivo studies have measured the axial movement of monofocal IOLs during accommodative effort by determining the difference between the anterior chamber depths in far and near fixation of the patients.[26] It has also been measured as the difference between anterior chamber depth during pharmacologic stimulation of ciliary body contraction with pilocarpine and during ciliary body relaxation with cycloplegia. Many of these studies have given contradictory results. In several studies of physiologic accommodation, the movement of the monofocal IOLs seems to be insufficient to provide significant accommodation. In contrast, in young pseudophakic patients, IOL movement has been shown to be a significant part of pseudoaccommodation.[27-31] When studied under pharmacologic stimulation of accommodation or of relaxation, most of the studies find a forward movement of the IOL, amounting to a few tenths of a millimeter. On the other hand, a backward movement of the IOL under pilocarpine has been reported. When compared with normal stimulus-induced movement, pharmacologically induced movement of the IOLs is greater (see Chapter 31). Consequently, it is not yet clear whether axial movement of the IOL has a role in pseudoaccommodation of monofocal IOLs.

Monovision

The phenomenon of apparent accommodation is not sufficient to provide spectacle independence for most patients implanted with monofocal IOLs.[32] Other methods provide a better near visual acuity for these patients. Monovision is a method of correcting presbyopia, where one eye is focused for distance vision and the other is focused for near (see Chapter 16). The earliest form of monovision is the use of a monocle spectacle lens, and this method has been widely used during the correction of presbyopia by contact lenses (see Chapter 14).

SUMMARY

Modern cataract surgery is a safe procedure with predictable refractive results that can be used for the removal of cataract as well as for the correction of refractive errors. Vision-threatening complications occur with only low frequencies, and the patients' visual rehabilitation after the surgery is rapid. Aspheric, toric, tinted, and several other types of monofocal IOLs offer solutions for the optimization of visual acuity and safety. Postoperative-acquired presbyopia affects most patients, although some have sufficient apparent accommodation to provide them with adequate unaided far and near vision. When using monofocal IOLs, monovision has proven to be a successful method for the reduction of spectacle dependence in patients' everyday lives. Use of the appropriate approach after careful patient selection is the key for achieving patient satisfaction after cataract surgery.

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