Refractive surgical corrective options after cataract surgery

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Abstract: Cataract surgery is one of the most commonly performed surgeries among the elderly today. The volume of cataract surgeries has dramatically increased in the past few decades due to technological advancements leading to decreased morbidity, better overall outcomes, and increased expectation for correction of refractive error and spectacle independence after cataract surgery. The number of cataract surgeries is expected to continue to rise with the increase of the elderly population. Thus, accurate predictions of intraocular lens (IOL) power and the ability to correct for any postoperative refractive errors are critical. Despite the improved ability of cataract surgeons to accurately calculate IOL power, postoperative refractive errors still do occur due to various reasons such as imperfect preoperative measurements, toric-lens misalignment, and existing or surgically-induced astigmatism. The aim of this article is to review the various surgical options, including intraocular and corneal refractive surgical approaches, to correct post-operative refractive errors after cataract surgery.

Keywords: Refractive surgery; cataract surgery; intraocular lenses (IOLs); laser refractive surgery

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Introduction

According to the World Health Organization, cataracts are the leading cause of blindness worldwide, affecting about 20 million people, and is responsible for 51% of blindness (1,2). The remarkable advances of cataract surgery in the last 20 years has led to an overall decreased rate of complications, time for visual rehabilitation, and improved outcomes of visual function. The decreased overall morbidity of surgery has allowed visually significant cataracts to be addressed earlier in the disease process to spare patients the previous period of significant visual impairment. In fact, there has been a trend of reduction in visual impairment threshold as indication for surgery in countries such as United States, Australia, Denmark, England, and Sweden (3). With the rapidly growing aging population, the number of people with cataract in the United States is projected to double from 24.4 million in 2010 to 50 million by 2050 (4).

In many developed nations, cataract surgery is the most frequently performed surgical procedure. The benefit of better visual function after cataract surgery in older populations has been demonstrated to be associated with decreased falls, increased independence, and better overall health (5). With various changes in the past two decades, such as improved technology and techniques, an aging demographic, increased life expectancy, increased second eye surgeries given decreased complications, cataract surgeries in the United States have increased by 20% between 2000 and 2010 (3,4). It is expected that the number of cataract surgeries performed will continue to grow. Thus, visual outcomes are increasingly important, especially as the cataract patient population is shifting to younger, independent individuals with less visual impairment. There are many reasons for poor visual outcome after cataract surgery, such as pre-existing eye disease, surgical or perioperative complications, and residual uncorrected refractive error. This article seeks to describe refractive surgical options to address residual refractive errors after cataract surgery.

Refraction correction via cataract surgery

Advances in technology and surgical techniques have significantly contributed to the improvement of refractive outcomes after cataract surgery over the past decades. The advent of small corneal incision cataract surgery has improved much of the corneal astigmatism induced by larger incisions of extracapsular cataract extraction and suture placement. In-the-bag intraocular lenses (IOLs) along with continuous curvilinear capsulorhexis surgical technique have also enhanced the predictability of lens position, thus reducing postoperative refractive surprise (6). In addition, advancements in preoperative measurements [axial length (AL) and keratometry] and availability of premium IOLs have further improved refractive outcomes of cataract surgery.

An estimated 2.5 million cataract surgeries are performed annually with the end goal of improving visual function (7). Currently, good refractive outcomes and relative spectacle independence is expected as the primary goal for many cataract surgeons and patients in developed nations (6-8). Therefore, improvements of refractive outcomes are crucial in fine-tuning refractive outcomes for patients (7). Careful preoperative surgical planning is imperative to achieving the desired emmetropic outcomes, and the most important element is accurate and reliable biometric measurements of AL and keratometry (8).

AL can be measured via two general methods: ultrasound and noncontact optical biometry. Ultrasound biometry is achieved via either contact applanation or immersion via a scleral shell. Contact ultrasound biometry has been the gold standard previously, but it has the disadvantage of introducing potential errors, such as off axis measurements or excessive indentation of the cornea. Newer optical biometry methods, such as the IOL Master (Carl Zeiss Meditec AG, Jena, Germany) and Lenstar LS 900 (Haag-Streit AG, Bern, Switzerland) uses laser partial coherence interferometry or low-coherence optical reflectometry, respectively, to measure the AL. These newer optical biometric methods allow for measurement of anterior chamber depth (ACD), which is also a contributing factor to final refractive power (8,9). According to Olsen *et al.*, ACD, AL, and corneal power contribute 42%, 36%, and 22% to refractive error, respectively (10). Due to this, surgical planning has improved over time with the invention of more accurate IOL power calculations. Third-generation formulae (Hoffer Q, SRK/T, Holladay 1) take in to account AL and corneal curvature. The Haigis formula (fourth-generation), on the other hand, takes in to account ACD and AL for its calculation. In a retrospective chart review, Yang *et al.* determined that the Hoffer Q formula performed better in eyes with ACD <2.5 mm and the Haigis formula was better prediction of the post-operative effective lens position in AL >24.5 mm and ACD ≥3.5 mm (9). While these formulae offer tremendous promise, 5% of eyes still result in >1 diopter deviation from target even with third and fourth generation formulae (7). Finally, choice of IOL is also an important factor of preoperative planning. Iwase *et al.* compared postoperative refractive changes in 339 eyes that underwent phacoemulsification cataract surgery with IOLs of different materials, rigid polymethylmethacrylate (PMMA), acrylic, or silicone. The eyes that received silicone IOLs had statistically significant myopic shift in the postoperative follow-up period with a mean shift of −0.53 D and the ACD was confirmed to be shortened (11).

Postoperative refractive errors in cataract surgery

Despite advances in preoperative planning, postoperative refractive errors still occur, for which there are many contributing factors. The most common cause of residual refractive error is due to inaccurate preoperative measurements (2,12,13). Lundstrom *et al.* examined 282,811 qualifying cases from the EUROQUO database to determine factors influencing postoperative refractive error. In this study, the absolute mean biometry prediction error was 0.42 diopters ±0.52 (SD). Biometry prediction error of ±0.5 D was seen in 72.7% of eyes and a prediction error of ±1.0 D was seen in 93.0% of eyes. A stepwise logistic regression with biometry prediction error greater than ±1.0 D revealed statistically significant correlations with patients with poor preoperative corrected distance visual acuity, higher absolute power of target refraction, coexisting ocular comorbidities (glaucoma, macular degeneration, diabetic retinopathy, amblyopia, and other eye diseases), prior corneal refractive surgery, and corneal opacities. These same factors also correlated with "refractive surprise", biometry prediction error greater than 2.0 diopters, in 3,555 eyes (13). Roszkowska *et al.* also showed that variations in IOL power calculations in eyes with comorbidities such as myopia and congenital lens abnormalities were the most common reason for post cataract surgery refractive errors followed by surgically-induced and pre-existing corneal astigmatism (12).

Correction of astigmatism adds another area of complexity to cataract surgery as astigmatic change is influenced by many parameters including refraction, anterior corneal astigmatism, posterior corneal astigmatism, IOL alignment, effective IOL toricity at the corneal plane, and three-dimensional IOL tilt that induces astigmatism in both toric and non-toric IOLs (14-16). Gunvant *et al.* found that the amount of astigmatism seen on preoperative manifest refraction, not corneal astigmatism measured by topography, was the most predictive of the need for postoperative correction (2). This indicates that total corneal astigmatism, not just anterior corneal astigmatism, has a major impact on the final refractive result. The total surgically-induced refractive astigmatism (SIA_{total}) includes two components, the surgically-induced astigmatism of the cornea (SIA_{cornea}) plus the surgically-induced astigmatism of the IOL (SIA_{IOL}). The SIA_{cornea} is the change in corneal astigmatism introduced via corneal incision that acts as a vector, with magnitude and meridional direction, that interacts with other existing vectors of corneal astigmatism. Corneal astigmatism is difficult to reliably measure and varies from case to case depending on the characteristics of incision, corneal radius, thickness, and rigidity. The impact of posterior corneal astigmatism has also been shown to add to against-the-rule astigmatism and compensate for with-the-rule astigmatism in eyes that underwent cataract surgery with temporal clear corneal incisions (16). The SIA_{IOL} is astigmatism introduced by the IOL, such as by misalignment or decentration (14). Significant refractive error can occur after toric IOL implantation, and it affects both patients with monofocal as well as multifocal IOLs (17).

One useful tool for analysis of post-operative results is an online toric IOL back-calculator, which allows determination of ideal IOL orientation from input of preoperative and postoperative information. Potvin *et al.* demonstrated insight into the nature of residual astigmatism using a toric IOL-back calculator in a specific patient population. This study analyzed 3,159 recordings and noted the differences in pre- and post-operative keratometry and intraoperative aberrometry to be important factors for residual astigmatism for these patients (18). The ability to identify sources of astigmatic error postoperatively using back-calculators is promising as it can be used when considering refractive corrections after cataract surgery.

Refractive surgical options after cataract surgery

IOL-based approach

Surgical refractive options after cataract surgery for spectacle independence is broadly separated in to two categories: IOL-based approach and corneal refractive surgery.

IOL exchange

For spherical power deviations, IOL exchange is an option. In a retrospective 14-year review of 49 eyes that underwent IOL exchange, it was shown that unacceptable refractive error was the third most common reason (13.33%) for IOL exchange in patients with anterior chamber IOLs (AC-IOL) and the second most common reason (5.7%) in patients with posterior chamber IOLs (PC-IOL). In this study, other indications for AC-IOL explantation were uveitis-glaucoma-hyphema (UGH) syndrome (26.67%) and persistent iritis (26.67%). The most common reason for IOL explantation in PC-IOL patients was IOL decentration/dislocation (85.3%) (19). Other reported indications for IOL exchange include IOL opacification, capsular phimosis, corneal decompensation, and glare (19,20). Marques *et al.* showed that vitreous prolapse was the major intraoperative complication that was seen in 13.3% eyes with AC-IOL and 11.7% eyes with PC-IOL when undergoing IOL explantation. Major postoperative complications were cystoid macular edema (20.0%), pseudophakic bullous keratopathy (6.67%), and worsening of age-related maculopathy (6.67%). In a prospective study of 128 eyes (113 patients), Leysen *et al* showed IOL explantation intraoperative complications including vitreous loss (18%), posterior capsule rupture (6%), zonular dehiscence (2%), and postoperative complications including IOP peaks (5%), secondary cataracts (3%), corneal erosion (2%), and retinal detachment (1%) (20). It's generally accepted that exchange for a PC-IOL is preferred when zonular support is adequate given AC-IOL's association with chronic iritis, UGH syndrome, uveitic glaucoma, corneal endothelial damage (19,21,22). Similar results for indications for IOL exchange, visual outcomes, and complications have been documented from other studies (15,19,20,23,24). Several authors have also recommended that a bimanual-type surgical system be used as it is crucial to plan for the ability to perform vitrectomy, and the surgeon should carefully consider back up approaches in the event of posterior capsular rupture, absent posterior capsule, or zonular dehiscence (19,21).

IOL explantation can be technically challenging with potential for complications, thus it's crucial for surgeons to be familiar with a variety of techniques and carefully consider the type of lens, type of haptics, and the details of the previous cataract surgery (20,21). Lens exchange within the first 4–6 weeks of the initial cataract surgery is generally easier technically as fibrosis around the lens will be present beyond this period of time (25). The initial key step of removing in-the-bag IOLs is to locate the space between the anterior capsule and the IOL. This space is generally most easily found at the haptic-optic junction. Then, using ophthalmic viscosurgical device (OVD) this space can be opened 360 degrees via viscodissection until the IOL freely rotates within the bag, and the IOL can then be prolapsed in to the anterior chamber. At this point, the surgeon must further manipulate the IOL in order to remove the IOL through a small corneal incision (<3 mm). Acrylic or foldable silicone IOLs afford the option of being refolded or cut in to smaller sections for explantation, non-foldable silicone lenses must be separated in to smaller pieces, and polymethyl methacrylate (PMMA) lenses must be explanted through an opening at least the size of the optic. For PC-IOL explantation and IOL exchange is a good option if unacceptable refractive error is noted in the immediate postoperative period. Special considerations must be made for AC IOL explantation as peripheral anterior synechiae (PAS) involving the haptics may lead to damage of the angle structures. It has been shown that it may be advantageous to fracture the haptics of AC-IOLs with intraocular scissors or preoperative Neodymium YAG laser for explantation (21,22).

IOL repositioning

IOL repositioning is also a viable option for poor optical outcomes in certain scenarios, such as decentration and malpositioned non-toric IOLs and misalignment of toric IOLs. Reopening the capsular bag and repositioning is generally tolerated in eyes without capsular tear or previous can-opener capsulotomy. IOL repositioning is also an option for patients with misaligned toric IOLs (22). Oshika *et al.* investigated 6,431 eyes that underwent cataract extraction with toric lens implantation. In this study, 42 (0.654%) cases underwent toric IOL repositioning due to symptomatic toric misalignment, and refractive cylinder was significantly reduced from 2.4±1.1 to 1.1±0.8 D. The authors recommended, based on this study and similar smaller previous studies, that reorientation be done between 1 to 3 weeks postoperatively as IOLs tended to rotate again when repositioned too early and was difficult to reposition later in the timeline due to capsular contraction (25).

Second posterior chamber IOL (piggyback IOL)

A second posterior chamber IOL (piggyback IOL) placement, in addition to the original IOL, is another option to neutralize postoperative refractive error. Implantation is technically easier and final refraction is more predictable with this method. Power calculation for a piggyback lens solely relies on the patient's pseudophakic refractive error and can be easily calculated with the postoperative spherical equivalent of pseudophakic refraction and the A-constant of the piggyback IOL. Piggyback lenses come in monofocal, multifocal, and toric varieties and are generally of low refractive power, range from −4.00 to +4.00 diopters, and can adequately neutralize most postoperative refractive errors within this range (26). The surgical techniques required to implant piggyback IOLs are also less demanding as the original IOL is left in place. Foldable piggyback IOLs can be inserted through 3 mm small incisions, directing an injector into the sulcus space or into the anterior chamber and subsequently dialed into the sulcus with surgical instruments (26).

A prospective nonrandomized trial by Kahraman *et al.*, reported outcomes of piggyback placement in 12 eyes of 10 patients. Complications observed were decentration in 1 eye (8.5%) and elevated IOL due to residual OVD in 1 eye (8.3%). There have been reports of interlenticular opacification (ILO) between two IOLs, which can cause a hyperopic shift and opacification of the visual axis. Kahraman *et al.* reported no complications involving ILO formation, and Scheimpflug photography showed stable distance between the two lenses throughout the follow-up period (27). There have also been reported cases of pigment dispersion syndrome, iris chafing syndrome, UGH syndrome, and corneal endothelial damage associated with square-edge piggyback lens implantation. Prior authors have indicated that using IOLs with round haptics/optic edges and 10 degrees of posterior angulation of haptics may decrease these complications. Kahraman *et al.* did not encounter any of these complications by using the recommended IOL design (27). However, surgeons should be aware of these potential complications and consider risk factors, such as history of pigment dispersion syndrome, ACD, and corneal endothelial health, of each individual patient.

El Awady *et al.* compared secondary piggyback implantation to IOL exchange for symptomatic residual ametropia after cataract surgery and found that, while both piggyback lenses and IOL exchange are associated with improved uncorrected visual acuity, IOL exchange is generally associated with more complications (23). Piggyback IOL implantation has been demonstrated as a safe procedure and is especially advantageous past the window of opportunity for exchange or repositioning as it reduces the risk of capsular bag and zonular damage, cyclodialysis, retinal tears, and macular edema (15,28). It is also an option for patients with primary IOLs that are difficult to exchange, unable to undergo corneal refractive surgery, or with hyperopic postoperative refractive error, which can be more reliably corrected via a piggyback lens than corneal refractive surgery (27).

Adjustable IOL

In the past decade, there has been much interest and development in various adjustable IOL technologies to afford noninvasive options to change optical power post-cataract surgery. These include light adjustable, mechanically adjustable, magnetically adjustable, wirelessly controlled liquid crystal IOLs (29,30). In November of 2017, the first adjustable IOL, a light adjustable IOL by RxSight Inc., was approved by the U.S. Food & Drug Administration (31). This technology contains photosensitive molecules to allow adjustment of the optical power postoperatively using specific patterns of UV light irradiation (32,33). Postoperative correction of up to 2 D spherical and cylinder change has been demonstrated to be effective and safe, and stable long-term with light-adjustable IOLs (33,34).

Laser-based corneal refractive approach

Laser-based corneal refractive surgeries, such as photorefractive keratectomy (PRK) and laser *in situ* keratomileusis (LASIK), have demonstrated great efficacy and predictability without a requirement of a second intraocular surgery. Roszkowska *et al.* examined 24 eyes with either high myopia or astigmatism (either pre-existing or surgically-induced at the time of cataract extraction) that underwent PRK after cataract extraction. Twenty-two cases had phacoemulsification with IOL implantation and two underwent extracapsular cataract extraction with IOL implantation. Twenty out of 24 eyes experienced residual refractive error after cataract surgery. With PRK enhancement, myopic patients' BCVA improved to a mean of 0.018±0.4 logMAR and astigmatic patients' BCVA improved to a mean of 0 logMAR (12). LASIK has also been established to be safe and effective by many studies (35-38). Fernandez-Buenaga *et al.* reported LASIK correction after cataract surgery to a spherical equivalent of ±0.50 D in 92.85% and ±1.00 D in 100% of eyes within target (37). An advantage of laser corneal refractive surgery is that the recovery time is generally less and the improvement in vision is usually faster than in secondary IOL-based surgery. However, corneal refractive surgery should only be considered if there is no ocular surface disease and residual refractive error from cataract surgery has stabilized.

While LASIK and PRK are safe and effective options for residual refractive error correction, patients with corneal abnormalities, dry eyes, and hyperopic residual errors are not ideal candidates due to risk of corneal ectasia, exacerbation of ocular surface disease, and inaccurate refractive outcomes. One well known complication associated with laser-based corneal refractive surgery is worsening of dry eyes, which is associated with surgical damage of corneal nerves. It has also been shown that corneal nerve damage and goblet cell damage occurs after cataract surgery (38). In a prospective randomized trial of 48 eyes that underwent phacoemulsification, it was found that corneal sensation returned to baseline at 3 months post-operation. However, goblet cell density showed persisting and significant decrease up to 3 months post-operation (38). Given the fact that most patients who undergo cataract surgery are older in age, it is likely that preexisting ocular surface dryness will be more significant in this population. Thus, the ocular surface of potential candidates should be optimized if corneal refractive surgery is to be considered.

IOL-based methods versus laser corneal refractive methods

IOL-based approaches have certain advantages as they can be done sooner after cataract surgery, are effective especially for large spherical errors, and do not require corneal surface alterations (15). Alternatively, laser-based corneal refractive surgery for ametropic correction is another option that has been shown to be effective, safe, and predictable with the advantage of preventing a second intraocular surgery. However, access to laser technology is limited in parts of the world, and it is not a viable option for high refractive errors and thin corneas (15).

In a retrospective review of 11 eyes that underwent cataract surgery with IOL implantation, Kuo *et al.* showed that excimer laser refractive surgery is safe, effective, and predictable for mitigating residual ametropia. However, the authors found that the uncorrected visual acuity in this study population was not as high as the general laser refractive patient population, potentially due to the older patient age of these patients or due to the prior cataract surgery (39). Several studies have also shown that laser refractive surgery has been shown to have better accuracy and predictability as compared to IOL exchange or piggyback lens insertion (15,31,34,35,40,41). Fernandez-Buenaga *et al.* found that while both LASIK and intraocular methods (IOL exchange and piggyback lens insertion) are effective, LASIK had superior efficacy and predictability as compared to intraocular approaches (37). In contrast, Jin *et al.* demonstrated that LASIK and intraocular methods were comparable in safety, efficacy, and predictability (42).

Given the variety of options available and risk-benefit profile, the choice of therapy should be guided by the clinical circumstance of the patient, the availability of technology, and the surgeon's preference and comfort in performing the selected procedure. Patients with hyperopic refractive error, abnormal corneal topography, and dry ocular surface may not be ideal candidates for corneal refractive surgery. Similarly, risk factors for complications should be recognized when choosing between piggyback implantation versus IOL exchange. Factors including ACD, corneal endothelial abnormalities, history of pigment dispersion syndrome, and duration since cataract surgery should be considered.

Discussion

Cataracts are one of the leading causes of vision loss worldwide and the number of cataract surgery has dramatically increased in the past several decades due to advancements in technology. The overall decrease in morbidity and improvements of outcomes has led to a marked increase in the number of surgeries being performed and a lowered threshold for cataract surgeries in younger and less visually-impaired patients. These trends have led to an expectation of refractive error correction through cataract surgery and post-operative spectacle independence for patients undergoing cataract surgery.

The predictability of refractive correction through cataract surgery has improved considerably. Accurate correction of refractive error hinges on several important factors including accurate AL and keratometric measurements and selection of appropriate formulas for IOL power calculation. One of the leading causes of residual postoperative refractive errors are inaccurate preoperative measurements. Existing corneal astigmatism, surgically induced corneal astigmatism, and IOL induced astigmatism, can introduce hard-to-predict refractive changes. Utilization of an online toric IOL back-calculator has been shown to be a useful tool to evaluate the optimal position of toric lenses using preoperative and postoperative information.

Surgical options for refractive error correction after cataract surgery can be broadly categorized into intraocular methods and corneal refractive methods. Intraocular surgical methods include toric IOL repositioning, IOL exchange, and introduction of a secondary "piggyback" IOL. These procedures can be performed early in the postoperative course and avoids permanent corneal alteration. More recently, the introduction of light-adjustable IOLs also presents a novel possibility of modifying IOL power without a repeated intraocular surgery. Corneal refractive procedures, including PRK and LASIK, is also another effective and safe option for postoperative refractive correction that has been demonstrated to be more predictable than a second intraocular surgery.

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