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Corrective Techniques and Future Directions for Treatment of Residual Refractive Error Following Cataract Surgery

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Abstract

Postoperative residual refractive error following cataract surgery is not an uncommon occurrence for a large proportion of modern-day patients. Residual refractive errors can be broadly classified into 3 main categories: myopic, hyperopic, and astigmatic. The degree to which a residual refractive error adversely affects a patient is dependent on the magnitude of the error, as well as the specific type of intraocular lens the patient possesses. There are a variety of strategies for resolving residual refractive errors that must be individualized for each specific patient scenario. In this review, the authors discuss contemporary methods for rectification of residual refractive error, along with their respective indications/contraindications, and efficacies.

Keywords

cataract; residual refractive error; ametropia; postoperative enhancement; Intraocular lens; IOL; Photorefractive keratectomy; Laser in situ keratomileusis

Introduction

Continual advancements and refinements related to technological aspects and techniques within cataract surgery have resulted in increasingly precise postoperative visual outcomes over time. Despite this encouraging trend, a significant proportion of patients are often left with a considerable amount of unintended ametropia which negatively affects vision [1, 2]. Primary reasons for development of residual refractive error include errors in biometry, which can subsequently affect the calculated intraocular lens (IOL) power, variation of postoperative IOL orientation, manufacturing inaccuracies, as well as uncorrected residual astigmatic error due to corneal irregularity or excessive rotational divergence of a toric IOL [3–6]. Disparagement of posterior corneal astigmatism during calculative determination of toric-lens power has also been implicated in development of residual astigmatic error [7].

Biometric measurements are typically performed through use of laser-based equipment, although ultrasonic methods are still necessary in certain circumstances. Although currently considered as having superior reliability for obtainment of axial length measurements, laser-based biometers are associated with measurement inaccuracies within eyes containing visually-obstructive aberrancies (i.e. corneal scarring, dense cataracts), as well as within patients with inadequate fixation during preoperative assessment (i.e. macular dysfunction) [3, 8]. Within such cases, preoperative evaluation with ultrasonic instrumentation may be preferable through use of either immersive or contact-based methods; with the former technique representing a more prevalent approach due to the avoidance of corneal deformation and resultant inconsistencies of measurement associated with the latter. Intraocular abnormalities may also contribute to biometric inaccuracies (i.e. posterior staphyloma, silicone oil). Miscommunication or inattention leading to inadvertent selection of incorrect IOL power represent less-common but important considerations, underlining the importance of intraoperative ‘time-out’ procedures for assuring confirmation of patient identification and associated operative procedural parameters. As postoperative visual outcomes have collectively improved, high patient expectations have also paralleled this progression, with the majority of patients expecting full spectacle independence at the conclusion of cataract surgery [9]. Achieving post-operative emmetropia is therefore highly desirable both for the surgeon and patient. There are currently an unprecedented number of treatment options for the correction of residual refractive error, each of which must be specifically tailored to the particular patient requiring treatment [10]. When procedures are appropriately implemented according to the specified clinical situation in question, patients typically experience favorable refractive outcomes. It is the objective of this review to briefly discuss preoperative and intraoperative considerations associated with residual refractive error, as well as summarization of present and future methods available for use in correcting this condition.

Preoperative Considerations

Preexisting systemic comorbidities and general ocular health are important parameters to assess preoperatively, as they can have a substantial impact on postoperative visual acuity [11]. Inaccuracies of topographic and keratometric measurements as a result of underlying corneal disease (i.e. Salzmann’s nodular degeneration, epithelial basement membrane dystrophy) can contribute to faulty IOL selection, and should be carefully assessed for. It is particularly important to assess for dry eye, blepharitis, and previous refractive surgery, due to the fact that each condition can predispose to development of residual refractive error. Preoperative treatment of blepharitis and dry eye are important for eliminating potential for preoperative biometric error and suboptimal postoperative outcomes [10–12]. In a recent large-scale study by Kugelberg et al., [13] decreased preoperative visual acuity, glaucoma, and female sex were all associated with a greater-than-expected deviation from the actual desired postoperative refraction. In patients who have undergone previous refractive surgery, there is an increased potential for development of residual refractive error due to inaccuracies associated with alterations of anterior keratometry values [14]. Consequential overestimation of corneal refractive power and alteration of refractive index values creates a higher propensity for post-procedural overcorrection [15]. It is therefore imperative to fully

assess each patient's medical history and whether any preexisting risk factors are present. After a comprehensive evaluation has been performed, an accurate assessment can be formulated and discussed with the patient regarding individual candidacy, probability of success, and expectations.

Intraoperative Considerations

Currently, there has been increasing emphasis on attempting to reduce residual refractive error through various intraoperative interventions utilizing modern technology. Intraoperative autorefraction is one such example that has been employed for helping to determine correct IOL power [16–18]. Intraoperative wavefront aberrometry is another form of technology that has been incorporated with the expectation of decreasing incidence of residual refractive error through improved estimation of existing spherical and cylindrical refractive error, thereby promoting a consequent improvement in selection of accurate IOL corrective power [19–21]. Although new wavefront technology appears promising, there have been questions raised regarding its true intraoperative reliability [22]. Notwithstanding various concerns regarding wavefront utilization, recent employment of intraoperative refractive biometry has demonstrated promising results for estimation of IOL power within patients with previously performed corneal refractive surgery [23].

Several intraoperative variables must be taken into consideration for accurate anticipation of postoperative refractive outcomes. Patients that have a significant amount of preoperative astigmatism may benefit from receiving limbal relaxing incisions at the time of cataract extraction, or insertion of a toric IOL [24]. A study conducted by Poll et al. [25] found that higher degrees of astigmatism fared more favorably with implantation of a toric IOL, opposed to limbal relaxing incisions. In addition to correction of preoperative astigmatic errors, an accurate estimation of surgically induced astigmatism (SIA) must be ascertained when inserting toric IOLs to prevent unexpected astigmatic residual refractive errors. Incision location, size, and use of sutures have all been associated with affecting the magnitude of SIA, with smaller incisions producing less iatrogenic astigmatism [26]. In addition, a recent study performed by Denoyer et al. [27] demonstrated an inverse relationship between corneal hysteresis and proportional degree of SIA, with higher preoperative corneal hysteresis values associated with decreased severity of SIA.

Keratoconjunctivitis sicca (KS) can also adversely affect postoperative visual acuity, and is commonly seen after cataract surgery [28]. There has been observation that cataract surgery can potentiate preexisting KS, and cause development of KS in previously asymptomatic patients [29]. It is thought that intraoperative periods of prolonged microscopic light-exposure can exacerbate and/or cause symptomatic KS, [29] and is an additional aspect that merits intraoperative consideration. Limbal relaxing incisions have also been associated with postoperative KS that should be closely monitored for postoperatively [30].

Postoperative Refractive Error

Underlying etiology of residual refractive error can be highly variable, and a thorough preoperative evaluation can usually aid in ruling out many potential precipitants (i.e. retinal disease, glaucoma, corneal disease/previous refractive surgery) [11]. Postoperative loss of

accommodation may be distressing to certain patients as well; an extensive preoperative explanation regarding postsurgical expectations will aid in decreasing apprehension related to this matter. Reasons for residual refractive error also vary according to which type of IOL has been implanted (i.e. monofocal, multifocal, or toric lens) [4, 31]. Development of posterior capsular opacification (PCO) can result in postoperative visual complaints irrespective of what type of IOL is used, however, different types of IOLs require different considerations. Accommodating IOLs are susceptible to gradual haptic deformation resulting from capsule fibrosis, culminating in the so-called 'z-syndrome' [32, 33]. In general, patients that have multifocal IOLs have higher sensitivity to minor degrees of postsurgical ametropia [34]. Potential problems specific to multifocal IOL implantation include lens decentration and small pupil size [34]. In cases of toric IOL implantation, axis misalignment must be taken into consideration as a possible cause of residual refractive error, despite being a relatively rare occurrence [21]. Increased pupil size in patients who are relatively younger can also be responsible for residual refractive error in cases of toric IOL implantation [35]. Certain IOLs have predispositions for development of specific types of residual refractive error, such as decreased quality of intermediate-distance vision in toric-multifocal IOLs, as well as higher-order aberrations (HOAs) such as glare, haloes, and decreased contrast sensitivity with multifocal IOLs [34, 36].

Initial corrective approaches for residual refractive error can be undertaken conservatively with implementation of spectacles, contact lenses, or dry-eye therapy [37, 38]. In direct comparison to artificial tear therapy, topical cyclosporine has demonstrated greater efficacy in resolution of postoperative KS with improved visual outcomes, according to a recent study [37]. Although this study initiated KS treatment 1 month preoperatively, their results are likely applicable to postoperative patients experiencing KS as well.

In the event that a patient cannot, or will not tolerate noninvasive corrective options (i.e. spectacles/contact lenses), or does not visually improve with KS therapy, alternate treatment options with a higher degree of invasiveness must be considered [39]. Strategies concerning surgical correction of residual refractive error fall into 2 general categories: corneal ablative procedures, and exchange, addition, or manipulation of IOLs (Figure 1). Each surgical treatment option will be discussed individually, along with respective benefits, risks, and appropriate patient stratification considerations.

Photorefractive Keratectomy (PRK)

Utilization of corneal ablation in combination with both pseudophakic and phakic IOL insertion is a technique that has been in practice for nearly 2 decades [40]. The term bioptics originally referred to correction of high refractive error through use of sequential phakic IOL implantation followed by laser in situ keratomileusis (LASIK). Whereas bioptics refers to a planned 2-step procedure to correct high amounts of ametropia, so-called 'unplanned bioptics' refers to unplanned corneal ablation following development of residual refractive error after a primary surgical procedure [40]. Performing corneal ablation to correct residual refractive error (unplanned bioptics) can be performed through various techniques, which all ultimately alter the corneal surface to improve refractive capability. It has been observed that LASIK and PRK have similar efficacy and reliability for correction of residual

refractive error following both phakic and pseudophakic IOL implantation [41–43]. Due to the high degree of homogeneity between the 2 procedures, other considerations must be taken into account in determining which procedure is optimal for the specific patient in question. In general, PRK is typically preferred for patients with preexisting KS, decreased corneal thickness, irregular astigmatism, and in some cases, inferior corneal steepening [41, 44–46]. In terms of safety, PRK and LASIK demonstrate excellent safety profiles, although diffuse lamellar keratitis (DLK), flap displacement, and stromal wrinkles have been known to occur after LASIK, which can each independently promote development of significant amounts of visual aberration [47–49]. Correction of myopic or astigmatic residual refractive error with PRK thus represents a viable alternative to LASIK for avoiding many of the aforementioned flap-related complications [50].

Laser in Situ Keratomileusis (LASIK)

LASIK has been widely studied regarding its utilization for correction of residual refractive error, and has demonstrated excellent efficacy, predictability, and safety [39, 51, 52]. Confirmation of refractive stability is of primary importance prior to implementation of LASIK-based enhancement. Although a definitive postoperative time-interval regarding optimal incisional stability has not been clearly established, a three-month duration is typically sufficient, provided refractive stability is present. Wavefront-guided LASIK procedures have been utilized for correction of residual refractive error in patients with multifocal IOLs with the expectation of achieving more precise refractive outcomes. Jendritza et al. [53] found that wavefront-guided LASIK demonstrated favorable efficacy when correcting for residual refractive error in patients with multifocal IOLs, but did not have a significant effect with respect to correction of HOAs. In addition, it was discovered that accurate measurement of wavefront aberrations is not possible in patients with refractive (opposed to diffractive) multifocal IOLs. In another study involving correction of residual refractive error in patients with multifocal IOLs, Muftuoglu et al. [54] did not find any significant difference regarding final visual outcome in patients who received wavefront-guided treatment compared to patients who received standard LASIK treatment. Irrespective of LASIK technique (wavefront/standard) or type of IOL (multifocal/monofocal/toric) used, correction of residual refractive error with LASIK typically produces excellent results. In a study comparing correction of residual refractive error in monofocal and multifocal IOLs, Piñero et al. [55] concluded that predictability related to achieving a spherical equivalent within ± 0.50 D after LASIK was higher in patients with monofocal IOLs, although this finding did not achieve statistical significance.

Studies comparing LASIK with IOL exchange and piggyback lens insertion have indicated that LASIK is superior for correction of cylindrical error, and also demonstrates greater precision in correction of residual refractive error than lens-based techniques. [56, 57] Specifically, LASIK-treated eyes have demonstrated superior predictability (92% of eyes within ± 0.50 D) when collated with lens-based procedures. [56] Performance of LASIK is preferable within patients who have undergone previous Neodymium:YAG (Nd:YAG) capsulotomy, due to the increased propensity of intraoperative complications within this patient population during IOL exchange. [57] Due to its wide applicability and extensively-studied profile pattern, LASIK remains as a very prevalent treatment option for the

correction of residual refractive error. Regardless of how broad a treatment's applicability, as always, individual patient characteristics must ultimately dictate which therapeutic treatment option is pursued (Table 1). As previously discussed, LASIK is not preferable for patients with preexisting KS or patients with decreased corneal thickness. Patients who have KS are an important group to consider, due to the fact that the majority of patients who undergo cataract surgery are of advanced age. This group of older patients is more likely to develop KS both as a function of age, as well as concomitant medication usage such as antihistamines and diuretics which are more commonly utilized within this population [58, 59].

Conductive Keratoplasty (CK)

CK is an alternative method of treatment for mild to moderate hyperopia resulting from residual refractive error. It has been approved by the US Food and Drug Administration (FDA) for correction of spherical hyperopia/presbyopia in patients 40 years old [60]. CK utilizes a heat-generating electrical current which denatures and contracts corneal collagen, resulting in central corneal steepening [61]. Indications for use of CK are more restrictive, with eligibility requiring low hyperopic refractive error with minimal cylindrical error (typically) in candidates. Although indications for CK have traditionally been reserved for correction of hyperopia, it has been demonstrated that CK is also a feasible option for correction of astigmatic errors in postsurgical eyes [62]. Presbyopic patients containing bilateral monofocal IOLs who desire spectacle independence can potentially benefit from CK, provided they are able to tolerate monovision [63]. Patients with previous refractive surgeries (LASIK, PRK) demonstrate a greater response to CK compared to patients without previous refractive surgery, and CK may be a preferable option in patients who have already undergone multiple previous ocular surgeries, due to its less invasive nature [64].

Aside from its limited scope of use, the primary drawback associated with the use of CK relates to the ephemerality of acquired refractive correction contemporaneous with the amount of regression that occurs postoperatively [65]. Although studies assessing refractive stability at up to 1 year have shown encouraging results, a long-term study assessing refractive stability at 6 years demonstrated near-complete regression of refractive effect [66]. Although the analyzed patient population was small in this study, it raises significant concern over the amount of actual permanence, if any, associated with this procedure.

Intraocular Lens Exchange

Problems concerning IOL dislocation/decentration as well as implantation of incorrect IOL power are currently the 2 most common indications for removal of foldable IOLs [67]. Patient dissatisfaction from residual refractive error resulting in HOAs such as glare and haloes constitutes an accruing underlying cause for IOL exchange. Increasing popularity and surgical implementation of multifocal IOLs are responsible for this rising trend, with a multifocal lens constituting the second most common explanted IOL, according to a 2007 international survey [67]. Another study performed by Jones et al. [68] revealed that 43.9% of total indications for IOL exchange were due to incorrect lens power/patient dissatisfaction. Patient dissatisfaction was related to glare/haloes and undesired visual

acuity, and within this group, two thirds of patients required IOL exchange of a multifocal lens.

IOL exchange is a procedure that is best performed within close proximity of initial IOL implantation, in an attempt to avoid gradual capsular-IOL adhesion that will invariably occur over time [69]. IOL exchange is preferable for patients who require large ametropic corrections, or patients with severe corneal disease who are not candidates for corneal ablative procedures [56, 57]. Timely IOL exchange after initial IOL implantation also decreases risk of additional procedures being implemented in the interim (i.e. Nd:YAG capsulotomy) and potentially creating further intraoperative risk for the patient. Nd:YAG capsulotomy has been strongly correlated with subsequent intraoperative vitreous loss in patients undergoing IOL exchange [70]. Additional risk factors involved with IOL exchange include posterior capsular rupture, zonular dehiscence, and retinal tears.

Piggyback Implantation

Incorporation of an additional IOL for correction of residual refractive error is another technique that has demonstrated good overall safety, reliability, and stability [71]. Advantages of implanting a supplemental IOL are similar to those of IOL exchange (correction of high refractive errors, corneal contraindications to ablative therapy), however, piggyback implantation also has advantages of being technically easier to perform relative to IOL exchange, as well as providing a more straightforward means of IOL power calculation opposed to IOL exchange [72]. Supplemental IOLs have the ability to correct spherical or cylindrical errors, and can be explanted if necessary. This feature of interchangeability can be advantageous for certain patient populations with variably changing refractive parameters (i.e. pediatric patients after cataract surgery, patients undergoing penetrating keratoplasty) [73]. Utilization of the piggyback method is typically performed by implanting the supplemental IOL within the ciliary sulcus to prevent interlenticular opacification (ILO) from occurring, which results from proliferation of cortical material in association with the anterior capsule [74]. ILO is a complication that is more prevalent in piggyback methods which utilize arrangement of two IOLs within the lens capsule, although there have been reported cases of long-term stability with this technique as well [75]. Secondary supplemental multifocal/toric multifocal IOLs have also been utilized in combination with existing monofocal IOLs with good results [73, 76, 77]. Despite production of specially formulated IOLs, which are designed specifically for sulcus insertion, several potential postoperative complications must be monitored for. These complications can include pupillary block, pigment dispersion, microhypema, or secondary glaucoma (uveitis-glaucoma-hypHEMA syndrome with low-grade inflammation) [78–80]. In accordance, piggyback implantation within patients containing pseudoexfoliation syndrome is contraindicated.

Anterior Optic Capture

Although only one small study about anterior capture has been reported, it will be briefly discussed as another potential strategy for correction of residual refractive error. Anterior optic capture is performed through anterior displacement of the optic, with haptic segments

left within the lens capsule [81]. It has been used for correction of mild hyperopic residual refractive error in patients with multifocal IOLs, and resulted in improved uncorrected distance visual acuity, with a postoperative decrease in uncorrected intermediate visual acuity. One patient developed glaucoma postoperatively, and underwent another operation to reposition the optic within the lens capsule. Other potential complications include pupillary capture, and increased risk of posterior capsule opacification. Further investigations involving larger patient populations are needed to elucidate the true utility of this technique.

Expert Commentary

Given the relatively high occurrence of residual refractive error, surgical treatment options are important components for every modern-day ophthalmologist to have within his or her armamentarium. Although laser ablative therapies along with techniques involving IOL manipulation have proved beneficial in treating residual refractive error, current emphasis regarding improvement in IOL design and intraoperative technology should prove valuable in significantly decreasing or perhaps someday eliminating residual refractive error altogether. Paradoxically, advances in recent technology have also proved problematic for the modern clinician, as patient expectations have gradually intensified to levels that are sometimes unattainable. Novel lens designs and surgical refractive techniques themselves can ironically later become the basis of the miscalculation of corneal refractive power or excessive amount of contrast insensitivity and inordinate glare a patient ultimately suffers from postoperatively. Additionally, implementation of contemporary intraoperative procedures such as wavefront aberrometry are not presently covered by Medicare or the majority of third-party payers [19, 82]. Patient candidacy for contemporary intraoperative treatment acquisition will ultimately be influenced by insurance viewpoints and a patient's individual financial capacity. In spite of recent technological developments, residual refractive error is an inevitability that will invariably affect a fixed proportion of postoperative patients with highly variable patient fulfillment in regard to preoperative expectations. It cannot be overemphasized how important preoperative patient communication becomes for appropriately managing patient expectations, and discussing options regarding potential postoperative outcomes.

Five-Year View

There is currently a preeminence being placed on eliminating HOAs and improving contrast sensitivity through preoperative customized selection of aspheric IOLs based upon an individual's specific category of corneal spherical aberration [83–87]. It is thought that implementing this strategy will lead to improved visual outcomes for patients in the future. There are also new intraoperative technologies emerging that are designed to reduce postoperative refractive disparity by enabling real-time analysis of residual refractive error and cylindrical axis. These technological advancements have the potential to substantially reduce or eliminate the incidence of residual refractive errors within the next five years. Application of femtosecond laser platforms for generating capsulorhexes containing greater symmetry and centration have demonstrated favorable results [88].

Inappropriately small or large capsulorhexes may contribute to postoperative capsular phimosis, or IOL decentration and/or tilt, respectively [89]. Higher predictability of postoperative IOL positioning resulting from utilization of femtosecond platforms appears to offer significant benefit during implantation of IOLs particularly sensitive to errors of misalignment, such as multifocal and toric IOLs. Another emerging method for correction of residual refractive error is through the use of light-adjustable lens technology. Light-adjustable IOLs utilize concentrated ultraviolet light to physically alter the IOL, which thereby revises its refractive properties for postsurgical adjustment in a non-invasive manner. Although not currently FDA approved (and therefore not clinically available), light-adjustable lenses appear to have encouraging potential for treatment of residual refractive error. Several studies have demonstrated use of light-adjustable lenses for correction of postsurgical myopic, hyperopic, and astigmatic errors [90–94]. Each of the aforementioned strategies is intended to grant the surgeon more control and precision in the selection of IOLs and in the execution of the operation itself, with the ultimate intent of achieving a more precise visual outcome for the patient. Time will tell whether this goal becomes realized.

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Key Issues

- Risk of residual refractive error can be minimized with careful preoperative evaluation
- Propensity, category, and mechanism of residual refractive error varies by IOL type
- Conservative, non-invasive treatment through use of spectacles or contact lenses should always be proposed as a first option
- Treatment modalities used for correction of residual refractive error must be customized to individual patient characteristics
- Advances in intraoperative technology have demonstrated potential to significantly reduce incidence of future cases of residual refractive error
- Preoperative communication with patients is critical in ensuring realistic postoperative expectations are realized

Figure 1. Management of postoperative residual refractive error

KS: Keratoconjunctivitis Sicca, IOL: Intraocular lens, DFE: Dilated Funduscopy Exam, CME: Cystoid Macular Edema, ERM: Epiretinal Membrane, DR: Diabetic Retinopathy, PCO: Posterior Capsular Opacification, PRRE: Postoperative Residual Refractive Error, LASIK: Laser in Situ Keratomileusis, PRK: Photorefractive Keratectomy, CK: Conductive Keratoplasty, NSAID: Non-Steroidal Anti-inflammatory Drug, PRP: Panretinal Photocoagulation, VEGF: Vascular Endothelial Growth Factor, Nd:YAG: Neodymium Yttrium Aluminum Garnet, SLE: Slit-lamp Examination

Table 1

Comparison of corrective techniques for PRRE

Procedure	Advantages	Disadvantages	Special Considerations
LASIK	-Wide applicability -Good efficacy/safety -Ideal for correction of astigmatic error	-Can cause/exacerbate dry eye symptoms -Can induce higher order aberrations	-Use with caution in patients with existing corneal disease/thinning -Contraindicated in patients with autoimmune disease
PRK	-Wide applicability -Can be used in patients with dry eye/thin corneas -Useful for correction of irregular astigmatic error	-Can Induce higher order aberrations -Longer recovery time compared to LASIK	
CK	-Minimally invasive	-Limited applicability -Postoperative regression	-Relative contraindication for patients with Sjögren's syndrome (risk of perforation)
IOL Exchange	-More effective for correction of large refractive errors -Ideal alternative for patients with severe corneal disease	-Invasive intraoperative procedure with attendant risks -Technically difficult	-Use caution in patients with previous Nd:YAG (predisposition for intraoperative vitreous loss) -Should be performed in close proximity of initial surgery
Piggyback Implantation	-Technically easier to perform -Reversible -Straightforward IOL power calculation -Wide applicability	-Potential for ILO -Risk for induction of uveitis/glaucoma	-Contraindicated in patients with pre-existing glaucoma/pseudoexfoliation syndrome
Anterior Optic Capture	-Can be utilized in areas with limited access to current technology	-Current lack or research regarding procedure -Increases risk of PCO -Risk of pupillary capture	-Requires further study

LASIK: Laser in Situ Keratomileusis, PRK: Photorefractive Keratectomy, CK: Conductive Keratoplasty, IOL: Intraocular lens, Nd:YAG: Neodymium Yttrium Aluminum Garnet, ILO: Interlenticular Opacification, PCO: Posterior Capsular Opacification