9 Multifocal Intraocular Lenses: Postimplantation Residual Refractive Error

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9.1 Introduction

After reading this chapter, you will have a better understanding of the following:

- *Why refractive surprises can occur after MFIOL implantation.*
- *The incidence of these errors.*
- *How you can best manage any surprises.*
- *How patient satisfaction can be elevated.*

Over the years, due to rapid technological advances and changing modes of practice patterns, cataract surgery has become a major form of refractive surgery. Novel microsurgical techniques, new IOL technologies, sophisticated biometry methods, and advanced methods of IOL power calculation allow most cataract patients to regain high-quality vision. As a result, indications for clear lens extraction has increased and patients have come to expect excellent unaided postop distance and near vision. With the introduction of multifocal intraocular lenses (MIOLs), many patients request and expect total spectacle independence for all visual tasks [1–3].

Overall, patient satisfaction scores after implantation of MIOLs are high. For example, using a 0–10 self-recording analogue scale, you can expect typical average satisfaction scores of 8.8 (Zeiss bifocal MIOL, $n = 48$, range 2–10) and 9.00 (Zeiss trifocal MIOL, $n = 52$, range 4–10). On closer examination satisfaction scores are closely linked to postop uncorrected distance, and intermediate, visual acuity as demonstrated in Fig. 9.1.

Despite all the advances, patient satisfaction is linked to the visual outcome and this, in turn, stems from any residual refractive error. A refractive surprise after cataract surgery is an unpleasant and frustrating situation for both the patient and the physician [1, 3, 4].

Presbyopia correcting IOLs are effective in restoring near vision after lens removal [5–9], but the outcome depends on several factors such as quality and accuracy of the surgical technique, astigmatism control, patient selection, efficacy of biometry and IOL power calculation [10–12]. A majority of patients implanted with such lenses are satisfied with the result [1, 2, 13, 14]. In spite of the optical tradeoffs, such as lower contrast

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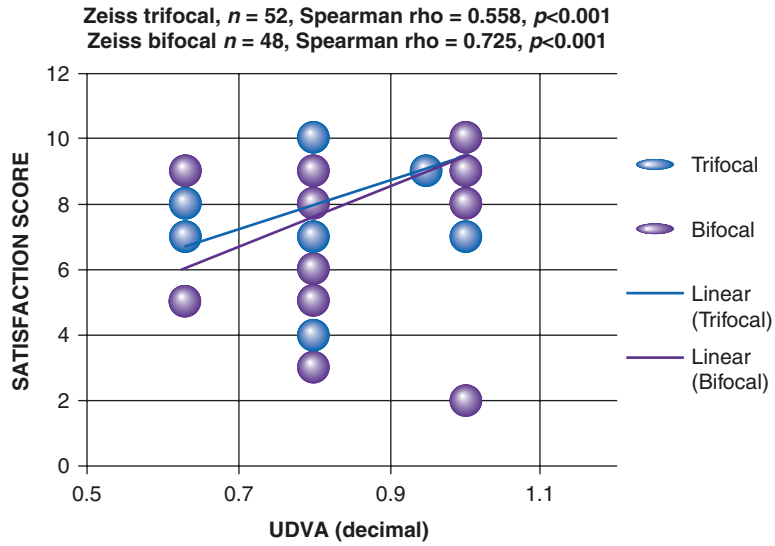

Fig. 9.1 Post-op uncorrected distance visual acuity and patient satisfaction

sensitivity or photic phenomena expected after their implantation, most patients either do not notice these downsides or understand and accept the compromise in quality that was required to achieve spectacle independence [15–18]. Advanced technology MIOLs tend to be less forgiving with respect to the surgical technique, MIOL power selection, ocular comorbidities and patient selection [19]. Comorbidities such as dry eye, vitreomacular pathology, or implant decentration may be tolerated in patients after a monofocal IOL implantation. However, these are much less tolerated by the multifocal IOL patients [19–25].

Presbyopia-correcting intraocular lenses should provide postop emmetropia for the best visual outcome, as small amounts of residual refractive errors can limit visual performance and jeopardize the result [1, 26].

Residual refractive astigmatism affects visual acuity and is a main cause of blurred vision after implantation of either monofocal or multifocal IOLs. The quality of the retinal image in patients implanted with MIOLs diminishes when over 0.75D of astigmatism remains uncorrected. They may also suffer from a severe decrease in overall quality of vision due to glare, halos, photophobia and diplopia [3, 23, 24, 26–28].

9.2 Causes of Residual Refractive Error

There are various reasons that can lead to residual refractive error after either the clear lens exchange or cataract surgery. They can be divided into pre-, intra- and postoperative categories [29].

Preoperative category include incorrect estimation of postoperative MIOL position, errors in axial length measurement, inappropriate selection of the MIOL power, limitations of the implant power calculation formulae (especially in extreme ametropia) and the lack of precision in the manufacture of an MIOL [30]. Patients that previously underwent any form of corneal refractive surgery may develop suboptimal results, in terms of hyperopic/myopic shift, because of the change in the optical profile of the cornea and, consequently, the errors in estimating corneal power and effective MIOL position [31].

Operative categories include surgical variations in the size and central position of the incision and capsulorhexis. These factors may influence the final position of the MIOL inside the bag and are surgeon dependent. Unintended surgically induced astigmatism (SIA) can also be a cause of refractive error after cataract surgery [32].

Postoperative categories that may influence refraction are related to wound healing, changes in corneal curvatures, displacement of the IOL resulting from postoperative capsular bag fibrosis and contraction [29, 33].

The various causes will influence not only the postop spherical refractive error but also astigmatism. It is estimated that 30% of patients undergoing cataract surgery or refractive lens exchange have corneal astigmatism exceeding 1.00D [34]. This percentage depends on the population under consideration, but toric MIOLs are available to compensate for corneal astigmatism [35, 36]. Residual astigmatism can persist following implantation with any form of toric IOL implantation. This may be because of any IOL rotation, malposition, cumulative errors in toric IOL power calculation, the effect of posterior corneal astigmatism and pupil size. Improving the precision of the surgical technique employed is expected to compensate for the first two issues. Raising the accuracy of toric MIOL power calculation by including the power, and axes, of both anterior and posterior corneal surface astigmatism should assist to nullify the effects of the third and fourth issues. Pupillometry ought to be considered especially in patients with relatively larger pupils such as in relatively younger patients who undergo toric IOL implantation [35].

After having said this, the following fundamental key question remains: What is the numerical value, and incidence, of a significant postop residual refractive error? An audit based on a random selection of 200 of our MIOL cases revealed 6.6% had residual astigmatism of 0.75 DC or above. A review of the appropriate literature points out that the typical margin of error in, or test-retest reliability associated with, subjective refraction ranges from ±0.34D to ±0.51D [37–39]. Various intrinsic factors can influence the outcome during a subjective sight test, e.g., attention, duration of concentrated visual task such as close work [40–42], eyelid pressure [43, 44], pupil size/depth of field [45]. Small shifts in sphere, astigmatic power and axis can be associated with these simple factors. These factors would be transient possibly diurnal [46]. Therefore, it is reasonable to accept, an unexpected postop residual refractive error of 0.50D or more should be regarded as significant. The sources of unexpected spherical errors are not difficult to identify. However, the same cannot be said for unexpected astigmatic errors following MIOL implantation. Figure 9.2 shows the incidence of unexpected astigmatism of 0.50 DC or more that was detected in patients that had been implanted with one of four different MIOLs, two toric and two non-toric. Ideally, for the non-toric MIOLs, the surgically induced astigmatism due to implantation alone should be near zero. However, this is not the case in about 25% of patients. Further analysis of the unexpected astigmatism [47] revealed, for the toric MIOLs the dioptric power and axis of the surgically induced astigmatism was, in general, linked with the power and axis of target induced

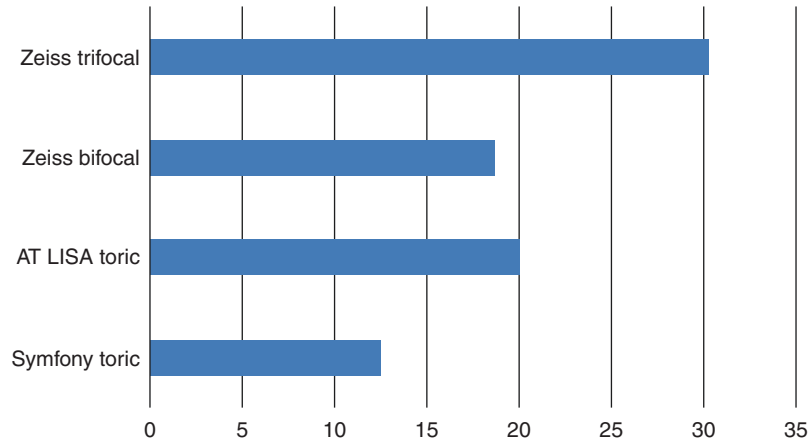

Fig. 9.2 Incidence percentage of unexpected astigmatism

astigmatism. In such cases the likely cause of the unexpected post-refractive error was probably associated with an error in the predicted, or manufactured, power of the implanted MIOL. For the non-toric MIOLs the axis of the surgically induced astigmatism was not correlated with either the axis or power of any preop astigmatism. However, the power of the surgically induced astigmatism was linked to the axis of any preop astigmatism. When the pre-op astigmatism is low, numerically no greater than −1.00 DC, and predominantly "against-the-rule," the surgically induced astigmatism can be up to −1.00 DC.

9.3 Management of Residual Refractive Error

Strategies for correcting any residual refractive error include spectacle correction and contact lenses. Corneal incisional procedures or enhancements with excimer laser (LASIK, PRK), conductive keratoplasty and lens based repeat surgery (IOL exchange, piggyback lenses) should also be considered when there is a strong desire to remain spectacle free [29].

9.3.1 Cornea-Based Surgery (Incisional Surgery, Laser Refractive Surgery)

Incisional techniques (e.g. astigmatic keratotomy and relaxing limbal incisions) are the easiest and most economically viable ways to address low amounts of residual astigmatism following monofocal IOL implantation. They can be very useful in older patients with dry eye disease. However, they should be avoided in MIOL cases because of poor predictability and regression [29, 48].

Correction of residual ametropia and adjustment of the final outcomes in pseudophakic patient with excimer laser corneal surgery is safe and predictable [49–57]. Laser refractive surgery avoids the trauma of intraocular surgery, provides greater flexibility and achieves satisfactory outcomes especially in cases of unexpected postop astigmatism. Treating such cases with LASIK is more predictable, safer, economically viable and yields less environmental waste compared with lens-based procedures [29, 49, 58]. In addition, LASIK is well tolerated in those cases that developed significant residual refractive error following yttrium aluminum garnet (YAG) capsulotomy [29, 59]. Once the LASIK flap has been established, additional optical adjustments can be performed successfully whenever necessary [29, 49, 59]. The two main limitations of laser refractive surgery are high postop refractive error and availability of technology [29, 49, 58].

An initial concern with excimer laser surgery after cataract extraction is the potential risk of submitting the patient to further invasive procedures. This is more of a concern in the older patient [58, 60]. This patient population is at greater risk of developing keratoconjunctivitis sicca and poor wound healing. Patients with certain systemic diseases, such as insulin-dependent diabetes, may have a higher risk of contracting infections or experience a delay during wound healing. The safety of LASIK and PRK in pseudophakic patients has been reported in several studies [49–57]. In general, corneal surgery, especially LASIK, should be performed 6–12 weeks after intraocular surgery because of potential complications related to the integrity of the original cataract incision, subclinical corneal edema and stability of the IOL. If, however, a residual refractive error is expected from the preoperative exam, a corneal flap can be cut prior to the lens surgery (a procedure referred to as bioptics). This allows for an earlier and less traumatic correction of the residual ametropia once the refractive error has stabilized [60].

LASIK treatments after cataract surgery have better outcomes in eyes implanted previously with monofocal IOLs than multifocal IOLs [50]. Selecting the correct treatment for excimer laser surgery after presbyopic IOL implantation can present a challenge to the surgeon. This may be because of the existence of errors in the estimation of residual refraction due to the presence of several foci and in the estimation of refraction after LASIK. This could be responsible for

artifacts in the subjective refraction because there were several refractive options providing a similar visual quality. The refraction may change depending on lighting conditions and pupil size in the multifocal IOLs [50].

The first step in assessing the refractive behavior of a premium IOL is to determine what type of IOL has been implanted. Regardless of the IOL design, preoperative evaluation of the intended correction with either trial frames or contact lenses under various lighting conditions will alleviate further refractive surprises. Muñoz et al. demonstrated that automatic refractometry, which is normally used as a starting point for subjective refraction, shows a strong tendency to produce more negative values, around 1.00D in sphere and 0.50D in cylinder values after implantation of a refractive multifocal IOL [61]. Retinoscopy has a slight tendency to provide more negative values in sphere and cylinder, generally below 0.50D, after the implantation of diffractive multifocal IOLs, whereas retinoscopy tends to be more reliable with annular refractive-based IOL designs [62]. Various methods for assessing the best subjective refraction in multifocal IOL patients have been proposed [50, 63].

There is a consensus that a starting point should be the patient's keratometric values since these are generally unaffected by MIOL implantation. The next step is to check visual acuity by evaluating the patient's defocus curve. Measurement of the defocus curve and estimating the best refractive correction to apply differs from author to author [50, 63].

Piñero et al. emphasized that a reference point for spherical subjective refraction should be established when refracting patients with MIOLs. This should be the midpoint of the interval of clear vision resulting from the depth of field provided by the MIOL to avoid further postoperative problems of predictability [50]. This midpoint can be easily determined by finding the range of spherical lenses powers that are tolerated by the patient when looking at, say, the 20/30 letter of Snellen chart. Then calculating the power of the spherical lens at the midpoint of this range. This midpoint point power is the reference corresponding with the correction that should be applied. This method could also be helpful and avoid mishaps when used as the reference point subjective refraction before selecting the MIOL power.

Mohammadi et al. presented a different approach. Their end point is to get the patient see 20/20 and J1 binocularly [63]. The authors suggest a binocular approach under high mesopic or photopic conditions. Their first step is to correct the keratometric cylinder error and place the corresponding sphere (i.e., half cylinder power) before the eye. In the second step they advocate refracting the right eye for the distance vision with a minus lenses, and the left eye for near vision with the plus lenses.

It could be thought that predictability of an excimer laser treatment in eyes implanted with multifocal IOL should be better using a wavefront-guided ablation because spherocylindrical errors and aberrations induced by the IOL (some are responsible for the depth of focus) are corrected at the same time. However, it has been proven that there are also problems inherent in the measurement of wavefront aberrations in eyes implanted with multifocal IOLs using Shack–Hartmann aberrometers [64]. Therefore, there is also a clear limitation for using wavefront-guided ablations after implantation of multifocal IOLs for the correction of residual aberration, not only for spherocylindrical but also for higher order errors [52, 65]. In our center, an audit of 823 MFIOL procedures revealed that 20 patients opted for an enhancement of their residual refractive error using a LASIK with Aberration Free program™ (Schwind Amaris 750S, Kleinostheim, Germany) at 3–6 months post-op. The mean spherical and cylindrical corrections were + 0.31DS (sd, ±0.86D, range −1.75DS to +2.00DS) and −0.89 DC (sd, ±0.69D, range −3.00 DC–0 DC) reducing to +0.05DS (sd, ±0.27D, range −0.25DS to +1.00DS) and −0.15 DC (sd, ±0.19D, range −0.50 DC–0 DC), respectively. The corrections were based on best subjective refraction. Figure 9.3 shows there was a concomitant improvement in both distance and near visual acuity as the refractive errors converged toward emmetropia. Enhancement using LASIK is a safe and efficacious procedure. And,

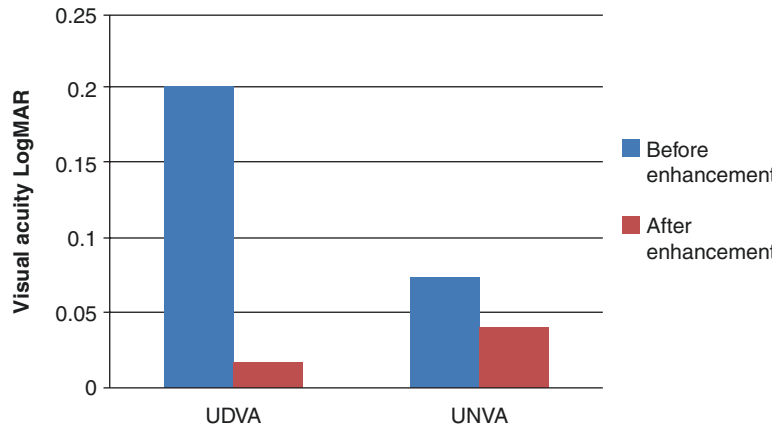

Fig. 9.3 Uncorrected distance and near visual acuity before and after enhancement

with reference to Fig. 9.1, a 0.3 unit improvement in UDVA is predicted to improve patient satisfaction scores from around 6 to 9.

9.3.2 Lens-Based Procedures (Intraocular Lens Exchange or Piggyback Intraocular Lens)

Lens-based procedures are preferable in some situations and provide some clear advantages [3, 29, 60, 66]. These are:

1. If there is a large postoperative refractive surprise as lens-based procedures are effective in reducing high degrees of spherical error.
2. Lens-based procedures hardly change the anterior corneal surface and do not significantly change the corneal refractive power.
3. The original cataract wound can be reopened and the IOL implanted soon after the initial surgery.
4. The need for special settings such as those required for laser refractive surgery is avoided.

However, the main drawback of an intraocular lens based procedure is the amount of induced astigmatism secondary to wound enlargement when explanting the original IOL or adding a piggy back IOL [49].

It has been reported that implanting an incorrect MIOL power is the second most frequent indication for lens exchange [67]. If the lens to be removed is foldable, it can be explanted and replaced through a small incision [68]. The piggyback technique involves the implantation of a second IOL in the posterior chamber of the same eye. It is easier than explanting and replacing the original IOL as sometimes the original IOL becomes attached to the capsular bag attempts at removal may cause rupture of the capsular bag, zonular damage leading to cyclodialysis, retinal tears and macular edema [69]. Implanting piggyback IOLs to correct residual ametropia is more likely to achieve emmetropia because the accuracy of the procedure is better than just IOL exchange [69]. With piggyback IOL implantation, it is not necessary to know the exact cause of the manifest residual refractive error. There is a risk that a replacement IOL does not rest at the same plane as the original MIOL after explanation. This would impact on the final refraction. Thus, implantation of a secondary piggyback IOL in the ciliary sulcus, leaving the original IOL in place, is more effective, well tolerated and relatively easier treatment for a pseudophakic refractive surprise [69]. Another advantage of a piggyback IOL is its reversibility without impacting on the original MIOL that remains in situ.

Another lens-based procedure is the light-adjustable IOL, which allows the possibility of correcting postoperative residual refractive errors in a, relatively, noninvasive way. After implantation and healing, fine-tuning of the refractive power can be performed using ultraviolet light based on the individual requirements of each patient. Up to two diopters of sphere, as well as cylinder, can be adjusted in one step [70]. For

now, the light-adjustable IOL is both expensive and available as a monofocal modality. The technology is there for it to be exploited and create a multifocal effect.

9.4 Conclusion

Modern cataract surgery with implantation of multifocal intraocular lenses raise patient expectations to full spectacle independence. Main causes of patient dissatisfaction are residual refractive error which can stem from variety of preoperative, intraoperative and postoperative causes. Postoperative residual refractive error can be treated conservatively (glasses, contact lenses) or surgically (laser vision correction, lens procedures). Further refinements in MIOL technology, biometric calculation and postoperative treatment (especially assessment of residual refractive error) are needed to further improve outcome and increase patients' satisfaction.

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Ethical approval: All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed consent: Informed consent was obtained from all individual participants included in the studies.

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