

# A Review of Presbyopia Treatment with Corneal Inlays

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## ABSTRACT

The prevalence of presbyopia continues to increase every year. The therapeutic approaches to presbyopia cover the spectrum of non-surgical to surgical techniques. With recent advances in biocompatible materials, corneal inlays make a strong case for their place within the treatment spectrum. This article takes a closer look at three of the current corneal inlay models: KAMRA, Raindrop, and Presbia Flexivue Micro-lens. Each design approach and mode of action is described with data from key clinical trials. Furthermore, the ability to choose the most suitable corneal inlay is presented by comparing each model and identifying their similarities and differences. The article then concludes by touching on the future of corneal inlays, looking at associated conditions and complications and how to manage them, as well as an expert's personal point of view of enhanced ideas for continuing the growth and success of corneal inlays in the market.

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## INTRODUCTION

Presbyopia is an age-related progressive decline in the crystalline lens' ability to accommodate, resulting in the inability to focus on near objects [1]. The impact presbyopia has on the quality of life on our aging global population has placed presbyopia treatment in the forefront of significant research [2]. With a projected prevalence of 2.1 billion people affected worldwide by 2020, combined with the documented negative health-related impacts, the treatment spectrum has been evolving rapidly [3–5].

The symptoms of presbyopia begin around the age of 40 years old [6]. One of the difficulties associated with presbyopia is that its pathophysiology remains poorly understood. The Helmholtz theory of accommodation is the most widely accepted proposed mechanism, which is based on the assumption that the change in the lens shape is due to the change in the ciliary muscle diameter. During accommodation, the ciliary muscle contracts, relaxing the tension on the zonular fibers, thus resulting in a reduced overall lens diameter. This relaxed zonular state allows the lens to obtain a more spherical shape, which leads to an overall

increase in refractive power. The opposite occurs in cycloplegia: when the ciliary muscle is relaxed, the tension on zonular fibers is increased causing the lens to assume a more flattened shape from the radial zonular tension. This accounts for the diminished power of the lens in cycloplegia [7]. There have been many other postulated theories of presbyopia to challenge Helmholtz's theory, yet not one has been universally accepted [8–10]. Dysfunctional lens syndrome is a term that is gaining more popularity in use for patient education and satisfaction. It is a simple method to describe the continuum of progression associated with age related crystalline lens changes that can help patients achieve a better grasp of their presbyopia [11].

The history of surgical presbyopia treatment has oscillated with numerous promising ideas that have fallen short of success. An early effort included addition of human donor corneal tissue to a patient's host cornea to change the refraction, a procedure called additive refractive keratoplasty [12]. Then, in 1949, we were introduced to Jose Barraquer's first corneal inlay prototype. Created for the treatment of high myopia or aphakia, it was designed from polymethylmethacrylate or flint glass. These early inlays showed initial signs of success in treating the targeted refractive error. However, the abhorrent rates of implant extrusion and corneal necrosis from reactions to the material quickly resulted in these inlays becoming out of favor [12–14].

Two decades after Barraquer experimented with his initial prototype, the concept was revived with the discovery of more biocompatible materials, like hydrogel [15]. These new materials showed promise in that they were transparent and permeable to fluids and nutrients, which provided some assurance the corneal tissue would tolerate them [16]. Unfortunately, the majority of these devices were explanted because of the aggressive rates of stromal thinning, melting, haze, inlay decentration, and corneal opacification [17–20].

With the current non-invasive methods of correcting presbyopia (i.e., bifocal or multifocal progressive spectacle lenses) falling out of favor because of the increased desire for spectacle

independence, we look toward the new generation of novel concepts of presbyopia treatment [13]. Presbyopia's therapeutic options have been employed through corneal, lenticular, and scleral surgical approaches in an effort to either enhance depth of focus or attempt to restore accommodation [21]. The purpose of this review is to provide an overview of corneal inlay-based procedures and devices currently in use for the surgical treatment of presbyopia.

This article is based on previously conducted studies and does not involve any new studies of human or animal subjects performed by any of the authors.

## CORNEAL INLAYS

Refractive surgery reached a milestone in innovation with the development and introduction of the new generation of corneal inlays for the treatment of presbyopia [13]. Using newer materials with enhanced biocompatibility alongside advances in technology (i.e., the Femtosecond Laser) has raised the ceiling of successful outcomes for our patients [22, 23]. Additional features of the inlays that have amplified their success include their thin design, small diameters, high nutrient and fluid permeability, and the capacity to be implanted relatively deep within the stromal tissue. Previous large and impermeable inlays disrupted the cornea's natural state by hindering natural metabolic functions. Depth of placement varies for each inlay design, given the different materials and mechanisms each provides. Inlays designed to utilize a small aperture or a different index of refraction are usually implanted deeper to avoid unintended changes in surface curvature, whereas inlays designed to deliberately modify the surface curvature are placed more superficially. It should be noted that there are inherent risks with surgical approaches, and one should consider balancing the positives and negatives between comfort and safety when discussing the surgical treatment of presbyopia with corneal inlays.

Another advantage of these corneal inlays is that they are additive and do not actually remove any tissue, which preserves the capacity

for reversal/removal or future options of any other type of presbyopia correction [4]. This is true only when there are no complications of corneal scarring, opacification, stromal thinning, or melting, which may occur in the aftermath of corneal surgery. After designated implantation in the non-dominant eye, inlay procedures can be combined with other refractive procedures. There tend to be fewer risks associated with the corneal inlay surgery compared to intraocular surgery, as these procedures are all limited to the cornea. With monovision, there is a one-to-one loss in distance vision for every line gained in near vision. However, with corneal inlays, the majority of patients lose only 1 or no lines of distance vision for about a 5–6 line improvement in near vision [24, 25].

The femtosecond laser offers consistency in terms of creating a more dependable flap or stromal pocket, which in turn provides improved accuracy of implantation depth and inlay centration [16, 26]. A major advantage of the pocket technique, compared to the flap technique, is the salvation of more peripheral corneal nerves. This defends against the diminished corneal sensation associated with flap creation, which in turn allows for a reduced incidence of dry eyes and a potential faster

visual recovery [26, 27]. Due to less tissue alteration, a pocket procedure is theoretically more biomechanically stable versus a lamellar procedure. Pockets are also less likely cause striae, which can be seen with lamellar flaps. However, lamellar flaps do have scenarios where they are more appealing than a pocket creation such as when an inlay is placed in combination with an excimer laser procedure to attain ametropia. The flap procedure is preferred as it allows for easy access in case the inlay is decentered or requires explantation [28]. Another option includes the creation of a stromal pocket roughly 100–120 microns deeper to a previous or sequential LASIK flap if refractive surgery is combined with the inlay at that time.

Currently, there are three available styles of corneal inlays: the Flexivue MicroLens™ (Presbia Coöperatief U.A., Irvine, CA, USA); the Raindrop® Near Vision Inlay (ReVision Optics, Lake Forest, CA, USA); the KAMRA™ inlay (AcuFocus Inc., Irvine, CA, USA) (Table 1).

## PRESBIA FLEXIVUE MICROLENS

The Flexivue MicroLens is a refractive optic corneal inlay that functions by altering the

**Table 1** Comparison of the three corneal inlays

	Diameter	Thickness	Flap/pocket placement	Mechanism of action	Centration	Material
Raindrop	2 mm	32 µm	120–200 µm	Increase central radius of curvature of overlying cornea	Central overlight constricted pupil	Hydrogel
Flexivue microLens	3 mm	15–20 µm	280–300 µm	Corneal multifocality (distance vision through a plano central zone surrounded by rings of varying additional power)	Placement over the first Purkinje image	Hydroxyethyl methacrylate and methyl methacrylate
KAMRA	3.8 mm with 1.6 mm central aperture	5 µm	200–250 µm	Increase depth of focus with pinhole principle	Placement over the first Purkinje Image	Poly-vinylidene Fluoride

corneal index of refraction to improve near vision performance, by the means of a bifocal optic, which separates distance and near focal points. The basic principle is corneal multifocality, providing distance vision through a plano central zone surrounded by 1 or more rings of varying additional power for intermediate and near vision [13, 26]. The Flexivue Microlens is a 3-mm-diameter, transparent hydrogel-based implant made from a hydrophilic copolymer of hydroxyethyl methacrylate and methyl methacrylate, and it contains an ultraviolet blocker. Depending on the add power, the thickness of the inlay varies from 15 to 20  $\mu\text{m}$  [13, 16, 28, 29]. The central zone is optically neutral with a refractive peripheral zone that provides add powers between +1.25 and +3.5 D, in +0.25 D increments. The central portion of the inlay has a 0.15-mm opening that facilitates fluid, nutrient, and oxygen transfer across the cornea [27]. The inlay material has a refractive power of 1.4583 and light at wavelengths above 410 nm have a transmission of 95% [13, 27]. The inlay is placed in a femtosecond created corneal pocket that is 280–300  $\mu\text{m}$  deep [28]. Centration of the Flexivue Microlens is based on placement over the first purkinje image. Given its relatively deep placement within the cornea, usually no corneal topography changes are seen.

To date, Presbia has implanted 1000+ inlays, including 421 implants in their US Investigational Device Exemption study. The Flexivue Microlens received its CE Mark in 2009. It is currently approved in 42 countries. Currently in the US, Presbia is in a Phase III trial for FDA approval and has completed enrollment.

In one study, Pallikaris et al. reported results on 43 patients with an average preoperative uncorrected distance visual acuity (UDVA) of 20/20 and an average uncorrected near visual acuity (UNVA) of 20/50. After 1 week, every patient had an increase in UNVA, and after 1 year 93% of patients were reported to have an UNVA of J2 or better [29]. Limnopoulou et al. reported the refractive outcomes of 47 presbyopic emmetropic patients who received the Flexivue Microlens over a 12-month period [27]. Their 1-year postoperative findings showed 75% of their patient's UNVA was 20/32 or better. The

UDVA showed a statistically significant decrease of 3 lines from preoperative (20/20) to postoperative (20/50) values. However, binocular UDVA did not show a statistically significant decrease. Measurements of best corrected distance visual acuity (CDVA) in the operative eye showed 37% lost 1 line, but no one lost 2 lines or more. There were no intra- or postoperative complications in this study, no inlay explantation or replacement, and no corneal tissue alterations on confocal microscopy. The study found a statistically significant increase in higher order aberrations and a statistically significant decrease in contrast sensitivity in both mesopic and photopic settings. Even though 12.5% of patients complained of glare and halos at the end of the 12-month period, the overall level of satisfaction and independence from spectacles was high [27].

## RAINDROP NEAR VISION INLAY

The Raindrop falls into the category of space-occupying corneal reshaping inlays that function to create a hyperprolate cornea. The Raindrop inlay is a clear lenticule made from hydrogel, which allows fluid, nutrients, and oxygen permeability, ensuring a stable corneal environment. The lenticular diameter is 2 mm with a central thickness of 32  $\mu\text{m}$ , decreasing to about 10  $\mu\text{m}$  in the periphery. The refractive index and water content of the Raindrop are approximately equal to the human cornea. The Raindrop itself has no actual refractive power. It is placed and centered over a light constricted pupil. When inserted under a LASIK flap or intracorneal pocket at a relatively shallow depth between 120 and 200  $\mu\text{m}$ , the anterior central radius of the curvature of the cornea overlying the inlay is increased. The induced hyperprolate shape with epithelial remodeling creates a multifocal cornea, improving both near and intermediate vision [30, 31]. The changes of the induced hyperprolate shape are appreciated on corneal topography scans, which demonstrate a profocal cornea. The pseudoaccommodative capacity of the Raindrop is enhanced with a constricted pupil, as the incoming light rays pass through the heightened cornea. Distance

vision is theoretically negligibly affected, especially with a dilated pupil, since the paracentral light rays are unaltered around the implant [28].

To date there have been about 4000–6000 Raindrop implanted worldwide. Raindrop has been approved for concurrent LASIK, pseudophakes, and emmetropes in the EU (2011), Singapore and Hong Kong (2011), South Korea (2014), Australia and New Zealand (2014). In the USA, Raindrop gained FDA approval in 2016.

Barragan Garza et al. published the first peer-reviewed paper about the Raindrop. Their prospective study followed 20 emmetropic patients with presbyopia for 12 months. Results at the end of the year showed an average UNVA 20/25 (0.1 logMAR) or better with the average UDVA 20/32 (0.2 logMAR) or better in the operated eye [30]. Besides one patient who was dissatisfied with the inlay and had it removed because of an UDVA of 20/50 (0.4 logMAR), the study overall showed high patient satisfaction with minimal effects on UDVA. Postoperative average photopic contrast sensitivity levels were similar to the preoperative values at both the 6- and 12-month visits and were considered to be within normal limits of a phakic eye [30, 32, 33]. At the end of the 12 months, 100% of patients stated they were very satisfied with their distance vision and the overall visual outcome, and 95% stated they were satisfied or very satisfied with the intermediate and near vision outcomes, while 84% reported that they never or rarely relied on glasses. Of note, the patient who had the Raindrop removed, returned to an UDVA of 20/20 (0.0 logMAR) by 1 month. The Raindrop confers the same adverse risks as the other corneal inlays, and besides the explantation, one patient required a repositioning [30].

Later Garza et al., enrolled 30 eyes to evaluate the efficacy of concurrently implanting the Raindrop with LASIK surgery in myopic presbyopes and then comparing these with results of the same treatment in emmetropic and hyperopic eyes [34]. At 6 months postoperatively, 93% of patients had binocular UNVA, UIVA, and UDVA of 20/25 or better [34]. This quickly established this procedure as safe and effective for treating presbyopic patients with myopia.

In one study, Chayet et al. looked at simultaneous refractive laser vision correction and Raindrop implantation. This prospective study enrolled 16 hyperopic presbyopic patients [35]. Results suggested a new indication for this implant. By the 1-week postoperative visit, 100% of patients achieved an UNVA of 20/32 or better. By the end of 1 year, mean monocular and binocular UNVA was 20/27 or better. Uncorrected intermediate and distance visual acuities were also satisfactory averaging 20/26 and 20/31, respectively [35]. There was one patient who suffered from recurrent haze and had the Raindrop explanted after 9 months. Overall 87% of patients stated being satisfied or very satisfied with their near, distance, and overall vision. Haloes and glares were studied, as they can be an issue for post-LASIK patients, and were found to be negligible in this study [35, 36]. Contrast sensitivity was not monitored in this study.

In another similar study of simultaneous LASIK combined with the hydrogel implant, greater than 80% of the enrolled 25 hyperopic presbyopes were found to have an UNVA of J1 or better. Uncorrected intermediate visual acuity was averaged at 20/25, which is an overall improvement of roughly 5 lines per patient. One patient had a loss of 1 line of UDVA, but overall UDVA averaged a 2-line improvement [37].

One series looking at 18 hyperopic eyes receiving the raindrop demonstrated an average improvement in UNVA of  $\geq 5$  lines 1 month postoperatively. Fourteen of the 18 (78%) implanted eyes were able to achieve an UNVA of 20/20 or better. There was an average improvement of 4 lines in UIVA, and the mean UDVA was 20/25 [38].

## KAMRA SMALL APERTURE INLAY

The KAMRA inlay functions to increase depth of focus with the use of the pinhole principle. The inlay has a total diameter of 3.8 mm with a central hole, or aperture, measuring 1.6 mm [39]. The small aperture effectively blocks bending rays of light, minimizing refraction, and thus increases depth of field. This improved

near vision is achieved without a significant change to distance vision. The opaque implant is made from an enhanced biomaterial, polyvinylidene fluoride, which only allows 6.7% of light transmission [13]. The KAMRA is only 6  $\mu\text{m}$  thick with 8400 laser-etched microperforated holes, 5 to 11  $\mu\text{m}$  in diameter, arranged in a pseudorandom pattern permitting adequate nutrient flow. The metabolic homeostasis attained with this implant avoids complications such as epithelial decompensation or corneal thinning. Centration of the KAMRA inlay is based on placement over the first purkinje image. Given its relatively deep placement within the cornea, usually no corneal topography changes are seen.

In 2005, the KAMRA inlay received the Conformité Européenne (CE) mark, which approved its use in the European Union. Outside of the USA, the KAMRA inlay is approved in over 50 countries, and estimates of over 20,000 worldwide implants have been recorded [4, 40]. With such a presence in the field, the KAMRA inlay is the most studied corneal inlay available. Like the other presbyopia-correcting inlays, the KAMRA inlay is implanted in the non-dominant eye in the line of sight. The depth of the lamellar pocket is usually around 250  $\mu\text{m}$ , unless previous LASIK has been performed, in which case a dual interface technique is employed, with the inlay placed about 100 to 110  $\mu\text{m}$  beneath the previous LASIK flap [28].

The KAMRA inlay improves near and intermediate visual acuity without a detrimental change in distance vision. The small aperture does not produce any splitting of light between the near, intermediate, and distance focal points, allowing a continuous range of vision. Stereoacuity is not significantly decreased either because the KAMRA inlay allows sufficient binocular input and does not blend vision [25, 41]. The KAMRA inlay has been used effectively in natural emmetropic patients, post-LASIK emmetropic patients, with LASIK correction as a simultaneous or two-step sequential procedure, and pseudophakic patients with a monofocal or phakic intraocular lens [5, 29, 35, 36, 39, 42–46]. The best refractive outcomes are seen in non-dominant eyes with a small amount of residual myopia,

–0.75D to –1.00D, with less than 0.75D of astigmatism and plano refraction in the dominant eye [5, 42, 43, 47].

Safety of the inlay has been well documented in human and animal studies. Standard risks of complications during refractive surgery are conferred to the KAMRA inlay. The healing response is a major risk of an adverse outcome with possible stromal thickening over the inlay causing a hyperopic shift from the flattened overlying epithelium [28]. Other adverse events have been reported such as corneal haze, epithelial iron deposition, and infectious keratitis [48, 49]. Unwanted outcomes can be handled by removing the inlay. There may be an associated shift in the patient's refraction, but the overall corrected visual acuity was not shown to change from preoperative measurements [39].

Many studies looking at the outcomes of the KAMRA inlay have been encouraging. Tomita and colleagues published findings of 223 post-LASIK eyes that received this inlay. At 6 months they showed a 4-line improvement in the mean UNVA (J8 to J2). Even though the mean UDVA showed a 1-line decrease after implantation, from 20/16 to 20/20, there was a high level of patient satisfaction in vision and spectacle independence [42]. In a different study by the same group, they looked at 360 eyes (180 patients) that received simultaneous LASIK and the KAMRA inlay in the treatment of emmetropes, hyperopes, and myopes [36]. This study helped assess the safety profile and efficacy associated with these two procedures performed simultaneously across all refractive errors. As expected, the preoperative mean UDVA and UNVA varied between each specific group but, at the end of the study, no significant difference was identified [36]. At 6 months, the emmetropic presbyopic patients had improvements of 6 lines in mean logMAR UNVA and 1 line in mean logMAR UDVA. The hyperopic presbyopes gained 7 and 3 lines, respectively. The myopic group showed 2- and 10-line improvements, respectively. Myopic patients who have relatively good UNVA had the smallest average gain of lines compared to their hyperopic and emmetropic counterparts, who were the most satisfied with spectacle independence and

overall vision [36]. Overall, the safety and efficacy of the simultaneous procedure were proven.

A study by Seyeddain et al. on 32 eyes reported 97% of patients reading at the J3 level or better in the operative eye [44]. After 24 months, the mean binocular UNVA improved from J6 preoperatively to J1. At 1 month, the mean UIVA was 20/20 and remained that way at the 24-month follow-up. The mean UDVA was reported to be 20/16 binocularly and 20/20 in the KAMRA implanted eye [44].

In the 4-year study by Yilmaz et al., reports on 39 emmetropic presbyopic patients implanted with the KAMRA inlay were collected. Twenty-seven of the patients achieved emmetropia from prior hyperopic LASIK; the other 12 were natural emmetropes. At 1-year follow-up, a large improvement was appreciated with the mean UNVA results showing an increase from J6 to J1+. The reports demonstrated an UNVA of J3 or better in 100% of patients and J1 or better in greater than 85% of patients [39]. With mean binocular UNVA results of J1 or better throughout the study, the reports were even more encouraging. The concern for adverse changes in UDVA were shown to be insignificant as the mean UDVA in eyes with the KAMRA implanted remained 20/20 throughout the 4 years. The UIVA was also satisfactory with 91% of patients seeing 20/32 or better [45]. This study did have three inlays explanted during its course, and even with small shifts from preoperative refraction measurements, there was no decrease in CDVA [39, 45].

The longest follow-up study of 5 years provided by Dexl et al. showed 32 emmetropic presbyopic patients with no statistically significant difference in refractive error after inlay placement [49]. The mean UNVA in the surgical eye improved significantly after 1 year from J7/J8 to J1, remained stable at J1 at the 36th month, and then decreased slightly to  $J3 \pm 2$  lines at 60 months. The mean UIVA followed a similar trend, improving from 20/32 to 20/25 at 12 months, remaining relatively stable at 20/20 until 36 months, and decreasing slightly to  $20/32 \pm 1.5$  lines by 60 months. A similar pattern was appreciated for both binocular UNVA and UIVA [49]. Mean UDVA in the

surgical eyes decreased from 20/16 to 20/20 at 12 months postoperatively, remained stable until 36 months at 20/20, and then had an additional decrease to 20/25 at the 60-month follow-up. There were a total of four adverse events reported during the course of the study: two decentered inlays required repositioning at 6 months, one patient had a hyperopic refractive shift with the KAMRA and had it explanted, and the other patient developed epithelial ingrowth shortly after implantation [49]. Besides a slight compromise in monocular and binocular UDVA, the overall mean monocular and binocular UNVA showed improvement.

Successful results in KAMRA inlay studies are attributed to some key factors. The newer commercially available model of the KAMRA inlay (ACI7000PDT) was improved from the previous model (ACI7000) by being manufactured as a thinner product (6  $\mu\text{m}$  instead of 10  $\mu\text{m}$ ). The change also decreased the average annulus light transmission value from 7.5% to 6.7%. The number of laser-etched holes increased from 1600 to 8400, but the diameter of the holes decreased from 25  $\mu\text{m}$  to  $\sim 5$  to 10  $\mu\text{m}$ . These model changes have reduced the overall visual disturbances patients experienced with the older model. Other factors include the method with which the KAMRA inlay is implanted. The creation of an intracorneal pocket with femtosecond laser technology salvages the number of corneal nerves affected compared to flap creation. This, in turn, diminishes the risk of dry eye disease and thus can improve outcomes. Use of the femtosecond offers its own advantages over the microkeratome, which include more predictable flap thickness, quicker visual recovery, and overall better UDVA results [50–52].

## COMPARISON

Each inlay presents its own unique way of correcting presbyopia. The Flexivue Microlens creates corneal multifocality by altering the corneal index of refraction to improve near vision performance. The 1.8-mm inlay has a plano central zone with increasing add power placed in the peripheral zones. It is made from

hydroxyethyl methacrylate and methyl methacrylate that contains an ultraviolet blocker. The Microlens is usually implanted at a depth between 280 and 300  $\mu\text{m}$ . The hydrogel Raindrop inlay has a 2 mm diameter with a central thickness of 32  $\mu\text{m}$ . This space-occupying inlay alters the eye's refractive power by increasing the cornea's central radius of curvature. Placed the most superficial of the three inlays, it is usually placed at a depth of about 30% of the total thickness of the cornea, typically ranging between 150 and 180  $\mu\text{m}$ . The polyvinylidene fluoride KAMRA inlay is only 5  $\mu\text{m}$  thick. With a total diameter of 3.8 mm, it contains a 1.6-mm central aperture that functions as a pinhole to increase depth of focus. Also placed relatively deeper within the stroma, the best outcomes come from a depth of 250 to 280  $\mu\text{m}$ , unless combined with LASIK, in which case it is placed at least 100  $\mu\text{m}$  beneath the LASIK flap.

Corneal inlays provide the refractive surgeon a method to correct presbyopia without the risks associated with intraocular surgery. They are exceptionally attractive with their capacity to provide a significant increase in near and intermediate vision without compromising distance vision. Based on the clinical evidence presented, all three inlays demonstrate a minimally invasive technique with tremendous results. Additional advantages include their capacity to be removed with no loss of best-corrected visual acuity and the fact that contrast sensitivity and stereoacuity are not significantly diminished. Some experts believe the Raindrop is best for patients with low levels of hyperopia and virgin eyes that have not undergone any prior refractive procedures. For KAMRA, myopic patients with refractions from  $-0.75$  to  $-1.00$  tend to do the best, and it can be performed after or simultaneously with LASIK.

## CONCLUSION

The future of corneal inlays could parallel the fast growth of the presbyopic population with the desire of being spectacle independent. As advancements in technology continue, a wider

variety of approaches is being seen with inlays. Results are promising with combined placement of an inlay with LASIK or with cataract surgery [53]. Selection is dependent on the surgeon's belief concerning which treatment is best for the patient, knowing that each inlay has its own set of disadvantages. Unpredictable wound healing and tear film dependence on final visual outcomes are other facets challenging the potential success of these products. Surgeons need to be familiar with results and treatment of this foreign body placed within the cornea, as well as minimize the amount of steroids needed to achieve this. Their future success depends upon advancements in the biocompatibility of the material used, decreasing the rate of complications and having more predictable outcomes. There is the possibility of a slight decrease in UDVA monocularly, but binocularly the patients are less likely to realize this decrease and overall have an increased satisfaction level with the outcomes.

Associated conditions and complications need to be prevented and managed appropriately. Surface disease management and improvement are critical for optimal function. Dry eye treatment has seen a recent surge of newer medicines and technologies to help those not finding relief with traditional conservative methods. Studies have shown patients with aqueous tear film deficiency finding symptomatic improvement with new drops like Restasis and Xidra. Minor non-invasive procedures with machines such as LipiFlow address both meibomian gland dysfunction and dry eye. Use of diagnostic instruments, such as the AcuTarget HD, allow the ophthalmologist to ascertain the surface health of the eye. Additionally, they provide pre- and postoperative Purkinje images that help guide and confirm placement of inlays into their appropriate positions.

Some experts in the field have discussed ideas of using anti-metabolite drugs in combination with inlays. Early results with surface ablation techniques, most commonly associated with PRK, showed astonishing results of corneal haze in as many as 10% of patients. Antimetabolites, such as mitomycin C (MMC), have been shown to be effective in preventing haze after PRK, thus making it a safe and reliable



procedure. The fear of haze induction after inlay placement can be mitigated with MMC to help prevent this complication from occurring. Further advances in corneal inlays are being innovated and studied with Presbyopic Allogenic Refractive Lenticule (PEARL) techniques using a SMILE lenticule as a corneal inlay [54].

There are three milestones in a patient's life from a refractive standpoint. The first is achieving ocular maturity with some degree of refractive error, the second is presbyopia during the 5th decade of life, and the third is development of cataracts. The first milestone is predictably corrected with an excimer laser, and the third milestone is successfully corrected with cataract surgery. An ideal solution for presbyopia correction is yet to exist. The ultimate challenge is the restoration of the crystalline lens with its natural accommodative properties. In the meantime, inlays can have a significant impact towards correcting the second visual milestone. Continued work is necessary to better understand the wound-healing characteristics of all inlays. As the actual inlays and method of insertion continue to improve, we expect that the safety and efficacy of corneal inlays will continue to improve and represent an excellent method to correct presbyopia.

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