A REVIEW OF THE SURGICAL OPTIONS FOR THE CORRECTION OF PRESBYOPIA

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Abstract

Presbyopia is an age-related eye condition where one of the signs is the reduction in the amplitude of accommodation, resulting in the loss of ability to change the eye's focus from far to near. It is the most common age-related ailments affecting everyone around their mid-forties. Methods for the correction of presbyopia include contact lens and spectacle options but the surgical correction of presbyopia still remains a significant challenge for refractive surgeons. Surgical strategies for dealing with presbyopia may be extraocular (corneal or scleral) or intraocular (removal and replacement of the crystalline lens or some type of treatment on the crystalline lens itself). There are however a number of limitations and considerations that have limited the widespread acceptance of surgical correction of presbyopia. Each surgical strategy presents its own unique set of advantages and disadvantages. For example lens removal and replacement with an intraocular lens may not be preferable in a young presbyopic patient without a refractive error. Similarly treatment on the crystalline lens may not be a suitable choice for a patient with early signs of cataract. This article is a review of the options available and those that are in development stages and are likely to be available in the near future for the surgical correction of presbyopia.

Key words: Presbyopia, multifocal, intraocular lens, accommodation, visual acuity, patient satisfaction, laser, excimer, femtosecond laser, dysphotopsia, cataract, clear lens extraction

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I. Introduction

Presbyopia is an age-related reduction in the amplitude of accommodation and leads to the loss of ability in changing the eyes focus between far and near. The correction of presbyopia without resorting to spectacles and contact lenses remains the Holy Grail for refractive surgeons as well as the billions of presbyopes.

Numerous accommodative and pseudo-accommodative approaches to treat presbyopia surgically exist. Each has its own benefits and limitations, and may involve some degree of compromise between the distance and near visual acuity (VA). Accommodative approaches attempt to restore the true, dynamic and continuous range of the defocusing ability of the eye. Pseudo-accommodative approaches provide functional near vision from a variety of non-accommodative factors.

This review provides an overview of the options that are currently available for the surgical management of presbyopia.

II. PSEUDO-ACCOMMODATIVE APPROACHES

1. Corneal Approaches

1.1. Excimer Laser Procedures

1.1.1 Monovision

Monovision with an excimer laser is a well-established technique that corrects one eye for distance (usually dominant eye) and the other eye for near, resulting in intentional anisometropia. (1) This aim is to give functional near and distant VA without the need for glasses. The mechanism that enables monovision to succeed is interocular blur suppression.

Studies have reported success rates ranging from 80-98% (1,2,3,4,5) for monovision post laser vision correction (LVC), 91% for monovision after cataract surgery and 95% following clear lens extraction (6) with good satisfaction. Surgically induced monovision is associated with a higher success rates than with contact lenses (91-98%), but it is unclear whether this is because it is harder to reverse the procedure or because of a multifocal corneal shape in LVC.

Limitations of monovosion include compromising visual function, such as reduced low contrast VA and sensitivity (CS), inability to incorporate an intermediate correction without compromising distance or near vision, reduced stereopsis, and small-angle esotropic shift. (2, 7, 8, 9)

1.1.2 Multifocal Corneal Ablation

Multifocality achieved by excimer ablation sometimes known as PresbyLasik, is interesting to refractive surgeons because it is familiar, seems less invasive than intraocular surgery and could theoretically be more controllable. However, this is against the conventional thinking for laser vision correction (LVC) where one usually attempts to minimise the higher order aberrations.

A variety of presbyopic LVC procedures exist. (10, 11, 12) In peripheral prebyopic LVC, the peripheral cornea is ablated to create negative peripheral asphericity. Thus the central cornea is for distance and mid-periphery for near vision (e.g. Nidek Advanced Vision Excimer Laser; (NIDEK Co Ltd, Gamagori, Japan). (11) In central presbyopic LVC, the central area is ablated for near vision and periphery for distance (e.g. Supracor, Technolas Perfect Vision GmbH, München, Germany); and Pulsar (CustomVis, CV Laser Pty Ltd, Perth, Australia).

Although optically the results are predictable and good, some patients find it difficult to adapt to the compromise and others are dissatisfied by the minor loss of distance VA. (12, 13)

Presbyond Laser Blended Vision (Carl Zeiss Meditec, Jena, Germany) is an optimised laser treatment method attempting to improve on conventional monovision. The dominant eye is treated for distance vision to almost plano and the non-dominant eye is corrected to be slightly myopic for near vision to -1.5D. This monovision treatment is enhanced by the use of a wavefront-optimised ablation profile to create a continuous refractive power gradient for the whole optical zone of the cornea. Studies show that this treatment is a well-tolerated and effective procedure for treating patients with presbyopia. (14,15,16)

More recently, SCHWIND eye-tech-solutions (Kleinostheim, Germany) introduced its PresbyMAX software. This is a bi-aspheric cornea modulation technique, based on the creation of a central hyper-positive area for near and leaving the peri-central cornea for far.

Uthoff et al. (17) reported good visual outcomes at distance and near in a 6-months follow-up study (table 1).

Whilst multifocal LVC represent a promising avenue for future presbyopic correction, outcome data is relatively sparse compared to other modalities. (7, 18)

1.2. Conductive Keratoplasty

Conductive Keratoplasty (CK) is the successor of Laser Thermokeratoplasty. CK uses the application of low frequency radio waves to “shrink” collagen fibrils within the mid-peripheral cornea. This causes a net steepening on the central cornea and thus increases the positive power of the eye. Radiofrequency energy is typically 0.6 W with a 0.6-second treatment time, (19) delivered through a fine tip inserted into the peripheral corneal stroma in a ring pattern outside of the visual axis. 8 to 32 treatment spots are placed in up to 3 rings in the corneal periphery (6-, 7-, and 8-mm optical zones) and striae form between the spots and create a band of tightening to steepen the cornea primarily to create monovision. Although this has shown to be a relatively safe technique and may present theoretical advantages over flap creation techniques (less invasive and no flap related complications), long-term studies report high rate of regression and hence this is not a popular technique at present. (20, 21, 22, 23)

1.3. Intrastromal Femtosecond Ring Incisions

Although the primary application of femtosecond laser has been its use in the creation of Laser-Assisted in situ Keratomileusis (LASIK) flaps, its precision and safety features make~~s~~ it a useful tool for many types of corneal refractive surgery, including intrastromal treatments. Typically, 5 concentric rings in the cornea stroma between 2 and 4mm from the line of sight are created using a femtosecond laser. Studies with INTRACOR (Technolas Perfect Vision GmbH, München, Germany) have shown the technique to be efficient and safe. (24, 25)

The main advantage of INTRACOR is that the corneal surface is not cut. The ring structure induces a localized biomechanical change in the tissue causing a slight central steepening of 1 to 2 diopters (D). This steepening changes the spherical aberration (SA) and corneal asphericity, resulting in near vision improvement. (24, 25, 26, 27) To date, the results reported have shown an overall improvement of uncorrected near VA (UCNVA). (24, 25, 26, 27, 28) However, some studies report no improvement in UCNVA at 1 month (25, 28), reduced best distance corrected VA (BDCVA), (26, 28) and anterior corneal protrusion after hyperopic LASIK followed by INTRACOR. (29) The treatment is usually performed in the non-dominant eye only. Further study is required on this treatment modality.

1.4. Corneal Inlays

Corneal Inlays (CI) are intrastromal implants which are placed underneath a LASIK flap or into a femtosecond laser created corneal pocket. The pocket technique has a number of potential advantages: the majority of peripheral corneal nerves are preserved, allowing corneal sensitivity to be maintained, they are additive, do not remove tissue, preserve future options for presbyopic correction and may be used in pseudophakia and/or combined with LVC. (30) In addition, they are all removable. The LASIK flap could be created with a microkeratome or with a femtosecond laser.

Complications reported with CI include hyperopic shift, haloes, a decrease in photopic and mesopic contrast sensitivity (CS), corneal thinning and melting, broadened defocus curve and reduced simulated retinal blur in the implanted eye (Kamra Inlay, AcuFocus, Irvine, CA) (31, 32, 33, 34). With all inlay designs, centration is critical for proper performance, and a small displacement can make a clinically significant difference. (35)

At present, there are three types of corneal inlays:

- CI that alter the index of refraction with a bifocal optic. The Flexivue Microlens, (Presbia, Los Angeles, CA) and Icolens (Neoptics AG, Hunenberg, Switzerland) both are currently in clinical trials although several presented studies. The Flexivue (precursor was the Invue) is the only CI utilizing a refractive addition power. (36)

The Icolens is a new CI and recently Baily has reported the one-year visual outcomes (Table 1). (37)

- The Raindrop Near Vision Inlay (ReVision Optics, Lake Forest, CA) is a CI that changes the corneal curvature. Garza et al. (38) reported good and stable results at 1 year. Table 1.

- The Kamra CI relies on small-aperture optics to increase the depth of focus. Most of the published data demonstrates that monocular implantation of a small-aperture inlay results in sustained improvement in near and intermediate vision while maintaining good distance vision. (31, 32, 33, 34) However, the size, material and visibility of the Kamra CI can be a disadvantage compared to the other CI.

2. Lenticular Approaches

The ultimate goal of cataract and clear lens extraction is to replace the crystalline lens with an intraocular lens (IOL) that simulates the original function of the crystalline lens and provides the patients with a full range of functional vision for all distances. Currently, the available IOLs can be grouped into accommodating (AIOLs) or pseudo-accommodating IOLs (although the mechanism of action of some ‘accommodative lenses’ may be pseudo-accommodative in nature). With pseudo-accommodative multifocal IOLs (MIOLs), the patient has 2 or 3 points in focus but primarily perceives only the focused image of interest. (39, 40)

Precise biometry, accurate IOL power calculation, good surgical technique as well as patient selection are crucial in achieving the best visual outcome and patient satisfaction.

2.1. Pseudophakic Multifocal Intraocular Lens

Multifocal Intraocular lenses are used following cataract patients or in clear lens extraction (41) and excellent clinical outcomes have been reported. (42, 43) However, patient dissatisfaction and secondary procedures, including IOL exchange, can also be significant. (44, 45) Some of the MIOLs are based on multifocal contact lens (CL) designs, however the visual results may defer between them. First, CLs and IOLs are placed in different location in the eye which results in different plane correction and second, the CL moves during the blink versus the stability of IOL. These differences could lead to different visual outcomes.

Complications of theses MIOLs lenses include reduction in quality of vision, especially loss of CS, dysphotopsia, and reduced intermediate and near vision. (46)

The discussion below is not an exhaustive list of the IOLs available or publications (it is beyond the scope of this article) but is representative for the common lenses used.

2.1.1. Refractive Multifocal Intraocular Lens

Refractive MIOLs have the incorporation of 2 different powers integrated into 2 or more typically circular refractive zones. Due to each lens zone having a different effective aperture, the image quality can depend on the pupillary response to light and the accommodation reflex. (47)

The ReZoom (AMO, Irvine, California, USA) is a refractive MIOL (the original model being called the ARRAY) and the FDA approved it in 2005. It is a three-piece MIOL and has five refractive optical zones; zones 1, 3, and 5 are adjusted for far vision, while zones 2 and 4 are adjusted for near vision. This design gives good distance vision and good intermediate range vision although the reading performance is variable. (48) Disadvantages of this lens, like many MIOLs, include dysphotopsia. (49)

The M-flex MIOL (Rayner IOLs Limited, Hove, UK) is based on a multi-zoned refractive aspheric optic technology, with either 4 or 5 annular zones (depending on IOL base power) providing +3.0D or +4.0D of additional refractive power at the IOL plane (equivalent to +2.25D or +3.0D at the spectacle plane). Cezon et al. (50) reported good visual performance and high rate of spectacle independence at 1 year.

Refractive MIOLs appear to be associated with more photic phenomena compared to diffractive MIOLs. (51) Photic phenomena are among the most frequent reasons for patient dissatisfaction following implantation of MIOLs. (44, 52)

2.1.2. Diffractive Multifocal Intraocular Lens

These are based on the principle of diffraction, whereby light slows down and changes direction when it encounters an obstacle. (53) These lenses use microscopic steps (diffractive zones) across the lens surface. As light encounters these steps, it is directed towards the distant and near focal points (the amount of light is directly related to the step height as a proportion of wavelength). Diffractive MIOLs can be subdivided into apodized (gradual reduction in diffractive step heights from centre to periphery) or non-apodized (uniform height): both categories are designed to reduce the severity of night halos compared to refractive MIOLs. (54) Examples include the ReSTOR (Alcon Lab Inc. Fort Worth, TX) (apodized) and Tecnis Multifocal (Abbott Medical Optics, Santa Ana, CA) and AT LISA 809 IOL (Carl Zeiss Meditec, Hennigsdorf, Germany) (both non-apodized). Most studies report good and stable distance and near vision, leading to low spectacle dependence and high patient satisfaction. (55, 56, 57) Although these designs have good visual outcomes, their weakest points can be their inability to provide good levels of vision at intermediate distance and loss of CS.

Aiming to improve intermediate vision, trifocal MIOL designs were introduced to the market: AT Lisa tri 839MP novel design (Carl Zeiss Meditec, Hennigsdorf, Germany), FineVision (PhysIOL SA, Liège, Belgium), and MIOL-Record trifocal IOL (Reper NN, Nizhny Novgorod, Russia). Results reported so far of theses lenses show a significant improvement in uncorrected VA at all distances. The trifocal designs may be the emerging technology in the field of the diffractive IOLs. (58, 59) The prevalence of complications still needs to be assessed with larger clinical studies.

2.1.3. Rotationally Asymmetric Multifocal Intraocular Lens

All traditional MIOLs are based on the concept of rotational symmetry. Recently, MIOLs with rotational asymmetry were introduced. One such lens, the Lentis MPlus LS-312 (Oculentis GmbH, Berlin, Germany), consists of a single-piece, aspheric surface that is independent of pupil size. (60) Different near additions are available allowing customisations for each individual and can be used with a mix and match philosophy.

Results indicate good distance, intermediate, and near VA with a high level of CS. (61, 62, 63) The authors recently conducted a study with the latest version: Lentis Mplus X LS-313 in 34 eyes showing excellent visual performance (64) (Table 2).

The SBL-3 MIOL (Lenstec, St. Petersburg, FL) is another asymmetric segmented MIOL that is also designed to improve CS, minimize dysphotopsias and provide good far, intermediate and near vision. The SBL-3 has a 3D sector-shaped add with a seamless transition zone between the distance and near segments. Venter et al. (65) recently published a study conducted in 106 eyes showing excellent outcomes (Table 2).

Rotationally asymmetric MIOLs seem to provide a good visual outcome at distance and near with minimal dysphotopsia and retain intermediate. The design minimises loss of light from splitting of the incoming light. Patients also were satisfied with their uncorrected near vision. Further studies with larger cohorts and longer follow-up period are necessary.

Finally, Staar (Staar Surgical Company, Monrovia, California) is known to be developing a new multi-focal phakic ICL that would potentially correct both ametropia and presbyopia.

2.2. Phakic Multifocal Intraocular Lens

The correction of ametropia and presbyopia can also be corrected using an anterior chamber phakic MIOLs. George Baikoff, designed one of the first models (66, 67) and this anterior chamber multifocal design has been marketed under the trade names of Newlife (IOLTECH, SA, La Rochelle, France) and Vivarte Presbyopic (CibaVision, Duluth, Georgia, USA) and provide a single addition of +2.5 D for near vision.

Baikoff and colleagues also performed the first clinical trial with this type of multifocal IOLs in 55 eyes showing that this IOL was effective and gave good predictability. (66) Alio and Mulet in another pilot study with a multifocal phakic IOL prototype (AMO, Irvine, California, USA) also showed good results (68). However, the complications reported by these anterior phakic IOLs include endophthalmitis, surgically induced astigmatism, corneal endothelial cell loss, pupil distortion, chronic uveitis, pupillary block glaucoma, pigment dispersion syndrome and cataracts.

III. ACCOMMODATIVE APPROACHES

For accommodation to be restored in the presbyopic eye, it is necessary that the ciliary muscle is still able to contract with accommodative effort: there is evidence to suggest that the ciliary muscle does not undergo atrophy with age and remains functional. (69, 70) Although the young phakic eye may have 7 to 8 D of true accommodation, most presbyopes would be happy with a restoration of 2-3 D of true accommodation.

1. Lenticular Approaches

1.1. Accommodating Intraocular Lens

There are many different concepts and designs for AIOLs including mouldable gels, fluid displacement and flexible haptics. These IOLs are designed to utilise ciliary muscle contraction, capsular bag elasticity and changes in vitreous cavity pressure to induce change or movement in the shape of the IOL to produce an optical change in the eye based on the optic-shift concept i.e. on the axial movement of the optic resulting from action of the ciliary muscle. A hinge between the optic and haptics allows the lens to move forward as the eye focuses on near objects and backward as the eye focuses on distant objects, thereby increasing the dioptric power of the pseudophakic eye.

It has been reported that an IOL optic shift of 1.0mm can offer about 1.0 D of accommodation in a single-optic IOL and between 2.5 to 3.0 D in an IOL with 2 lens optics (71, 72) In addition, the amount of accommodative result depends on several factors, such as the position of the optics in the capsular bag, the posterior chamber and the refractive power of the IOL.

The Crystalens HD [Bausch & Lomb), Rochester, NY] the Tetraflex HD (Lenstec Inc. St. Petersburg, FL) and the 1CU Human Optics (Human Optics AG, Erlangen, Germany) are examples of single optic AIOLs and have all been extensively used). (73, 74, 75) Visual performance reported with these AIOLs is promising (73, 74, 75), however capsule opacification and loss of accommodative ability with time are often present.

The single-optic passive-shift IOLs are considered pseudo-accommodative because have limited accommodative ability, as its anterior movement is insufficient to provide functionally significant amplitudes of accommodation. Hence, dual-optic devices were developed such as the Synchrony (AMO, Irvine, CA), and the Sarfarazi IOL (Shenasa Medical LLC, Carlsbad, CA). The configuration of these devices with a high positively powered mobile anterior optic, connected to a stationary negatively powered posterior optic, is designed to increase the potential accommodative amplitude. Published results of both IOLs are limited but have shown positive results in small cohorts. (76) They may be technically relatively difficult to handle.

In regards with IOLs, which change their shape or curvature with accommodative effort, there are some in different stages of development. The FluidVision lens (PowerVision, Inc. Belmont, CA) drives fluid of a polymer-matched refractive index from the IOL’s soft haptics through channels to a fluid-driven internal activator. One-year follow-up showed that the base IOL powers were accurate and stable, visual acuities were good, and patients showed more than 5.00 D of accommodation on average (ASCRS 2011). The NuLens (NuLens Ltd., Herzliya Pituah, Israel) is a sulcus-based accommodating IOL is still under development although it has been implanted in 10 eyes with cataract and atrophic macular degeneration showing at 1 year reporting this IOL may result up 10D of accommodation, (77) and the Superior Accommodating IOL (Human Optics AG, Erlangen, Germany) is designed to mimic the behaviour of natural lens and it is under development.

The lens filling techniques are being under investigation for years. It consists in replacing the lens with a soft gel that would allow modifying the shape for accommodation. The Medennium SmartLens IOL (Medennium, Inc. Irvine, CA) is a “smart” hydrophobic acrylic material with unique thermodynamic property. When implanted into the capsular bag, the body’s temperature causes the material to transform into a gel-like polymer and take the shape of the natural lens. To the knowledge of the authors no data has been yet published. It should be noted that objective measurement of the accommodative capability of AIOLs is extremely difficult to obtain. (78)

1.2. Lens Softening

“Softening” of the less elastic presbyopic crystalline lens is one of the newest approaches to restore accommodation. There have been some pharmaceutical attempts to act selectively on the lens and soften it, however, to the knowledge of the authors this is not a viable alternative.

The femtosecond laser seeks to restore the flexibility that has been lost by making precise incisions patterns within the lens without opening the capsule.

Pre-clinical studies have been performed in human cadaver and animal lenses (79, 80, 81, 82) which demonstrated safety, increased flexibility of lens and no production of cataract. A feasibility study with the LENSAR (LENSAR INC, Orlando, FL) in 80 subjects with cataract showed that one third showed an improvement in objective accommodation measured with the Grand Seiko WR-5100K autorefractor (Grand Seiko Co, Ltd, Fukuyama, Japan) and over 50% showed an improvement in subjective accommodation with the push-down method. Over 40% also showed an increase in the BDCNVA (results presented at ASCRS 2014).

Currently, there is another femtosecond laser based therapy study for the treatment of presbyopia in Germany (The Human Eye study Cologne/Rostock). This clinical study is beeing conducted in 2 sites: University of Rostock University Eye Hospital, Rostock, Germany and Augenklinik am Neumarkt, Köln, Germany. Fifteen eyes in each site (n = 30 eyes) have been recruited. However, to the knowledge of the authors, no data has been reported.

2. Scleral Modification

Extraocular approaches have been developed based on Schachar’s theory. (83) This model states that accommodation results of an increase of zonular traction at the lens equator to increase the lens diameter, therefore, presbyopia occurs as a result of increased lens growth causing a reduction in the space between the lens and the ciliary body (circumlenticular space, CLS), such that upon contraction the zonules can no longer exert their effect on the lens due to a loss of tension. Magnetic Resonance Imaging (MRI) studies have shown that the CLS decreases with age as a result of the inward movement of the ciliary muscle ring that occurs with advancing age and an increase of the lens thickness. (70) However, goniovideography, infrared photography and MRI studies have shown that the lens decreases in diameter and surface area with accommodation. (84) Despite the controversy of this theory, Schachar postulated that expanding the dimensions of the overlying scleral wall, by pulling the ciliary muscle away from the equatorial edge of the lens, would reverse the process of presbyopia and increase accommodative amplitude. LaserACE (Ace Vision Group, Silver Lake, OH) and PresVIEW Scleral Implants (Refocus Group, Dallas, TX) were originally developed on the basis of this theory but the actual mechanism of action is still under investigation.

2.1. Laser-Assisted Presbyopia Reversal

Laser assisted presbyopia reversal (LAPR) aims to restore dynamic accommodation increasing pliability in the sclera and increasing net forces of the ciliary muscles on the lens facilitating accommodation. LAPR mechanism of action objective is decrease the ocular rigidity utilizing a hand held fibre optic piece that delivers pulses using an erbium-YAG laser to ablate 600-μm laser spots in the sclera, which are presumed to decrease the distance between the ora serrata and the scleral spur, restore the anatomical relationships of the system and free the ciliary muscle to contract normally. The spots delivered in a diamond matrix pattern of 9 laser spots into each oblique quadrant. The results so far (in 134 eyes of 67 patients after 18 months follow-up are promising. Hipsley reported restoration of 1.25 to 1.75 D of objective accommodation, which remained stable through 18 months in initial results (2011 ASCRS meeting). Table 1

2.2. Scleral Expansion Bands

Scleral expansion band (SEB) surgery for the treatment for presbyopia is based on the model of accommodation theorised by Schachar. (83)

SEBs have therefore been utilised for this purpose, but previous studies have demonstrated mixed results and have demonstrated limited success with temporary improvement in amplitude of accommodation. (85, 86, 87) Most recently, Refocus group has developed The PresView scleral implants. The technique consists of implanting four prostheses (size of a grain of rice) within elongated pockets in the sclera. The prostheses are thought to exert traction on the sclera in the region overlying the ciliary body which expands the sclera and the underlying ciliary body: thus restoring the effective working distance of the ciliary muscle and increasing the amplitude of accommodation. The actual surgical technique has evolved markedly from the initial use of manual diamond blade to the current use of disposable scleratome improving considerably the accuracy of the tunnel creation. Furthermore, the original implant was a one-piece device, which was pushed into place and was difficult to thread through the tunnel. This one-single piece had a tendency to slip out of the tunnel over the long term resulting in a return or regression of patients' preoperative near vision. Nowadays, the implant is a two-piece locking implant that prevents the implant from slipping out. Currently, Refocus group is conducting a FDA clinical trial. Table 1

IV. Conclusion

There have been significant developments in surgery for presbyopia over the last decade achieving relatively good outcomes but each modality has its own advantages and disadvantages and sometimes compromises. However, to properly compare interventions it is necessary to encourage researchers to report BDCNVA rather just UCNVA to minimise any confounding effect of myopia and astigmatism on results.

Other options for the management of presbyopia should not be forgotten, for example, it has been suggested that the use of miotics to increase depth of focus could help those suffering from presbyopia, and this would represent a type of reversible treatment. However there is little published evidence with this form of treatment, although 200 emmetropic eyes have been reported as having been treated in South America. (88)

In the next few years it is likely that the introduction of different IOLs will be seen, as well as the development of new pharmacological treatments and technologies to provide patients with better visual outcomes and then possibly restoration of true accommodation to the presbyopic eye will be seen.

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Author	Procedure	Study Design	Number of eyes	UCNVA	BDCNVA	Additional tests	Complications
Levinger (2013)	Monovision induced by LASIK	1 year	38	0.06 logMAR (binocular	Not available	• CS reduced in mesopic condition. • Near stereoacuity 57 seconds of arc • 85.2% of satisfaction	Not reported
Greenbaum (2002)	Monovision pseudophakia	1 year	120 cataract/20 CLE	0.0 logMAR or better (binocular) in 91% cataract & 95% CLE	Not available	• 91% acceptance cataract • 95% acceptance CLE	• 1 dry eye, • 1 vitreous loss • 1 iris atrophy • 20% reported halos & glare in cataract in CLE
Uthoff (2012)	Multifocal corneal ablation	6 months	20 (emmetropic), 20 (hyperopic), 20 (myopic)	0.18 logRAD (emmetropic), 0.24 logRAD (hyperopic), 0.12 logRAD (myopic) binocular	Not available	CS significantly reduced in all groups	Not reported
McDonald (2004)	Conductive Keratoplasty	6 months	143	0.18 logMAR or better in 77% (monocular)	Not available	76% reported very satisfied/satisfied	Not reported
Menassa (2012)	Intrastromal femtosecond Ring Incision	18 months	25	0.2 logMAR (monocular)	Not available	Corneal steepening 0.90D	• 36% reported rings aroud light sources
Limnopoulou (2013)	Flexivue Microlens Inlay	1 year	47	0.14 logMAR (monocular), 0.13 logMAR (binocular)	Not available	• HOA increased. • CS decreased. • 81.25% reported • UCNVA excellent	Not surgical complications
Garza (2013)	The Raindrop Inlay	1 year	20	<0.1 logMAR (monocular & binocular)	Not available	• Photopic CS no significant change. • 95% reported satisfied or very satisfied UCNVA, UCIVA. • 100% satisfied or very satisfied UCDVA	• 1 patient reported severe halos at 6 months, • 10% inlays removed because dissatisfaction, decentation.
Seyeddain (2013)	The Kamra Inlay	2 years prospective	24	0.1 logMAR (monocular)	Not available	0.1 logMAR UCIVA	• 1 eye with epitheial ingrowth in the pocket • 1eye with epitheial iron deposit

Baily (2014)	The Icolens corneal inlay	1 year	52	0.4 logMAR (monocular)	Not available	90% reported happy with the procedure	11 inlay explanted because minimal improvement UCNVA
Hipsley (ASCRS 2011)	The LaserACE procedure	18 months	134	0.18 logMAR or better in 89%	Not available	• 1.25-1.75D increase in objective accommodation. • 0.18 logMAR or better in 95% UCIVA	No major complications
Sunil Shah	PresVIEW$^{\text{TM}}$ Scleral Implant	3 months (on going 2 years FDA clinical trial)	28	Not available	0.3 logMAR 100% (monocular, binocular)	Mean lines of improvement at near 2.3 monocular & 2.0 binocular	Not reported

*Note: some visual acuities were converted to logMAR using the Visual acuity conversion chart prepared by Jack T Holland

LogMAR: Log Minimum Angle of Resolution
CLE: Clear Lens Extraction
UCNVA: Uncorrected near visual acuity
BDCNVA: Best distance corrected near visual acuity
CS: Contrast Sensitivity
HOA: High order aberration
UCIVA: Uncorrected intermidiate visual acuity

Table 1. Visual outcomes of Presbyopia procedures

Author	**IOL**	**Design**	**Study Design**	**Number of eyes**	**UCNVA**	**BDCNVA**	**Additional tests**	**Complications**
Forte (2009)	ReZoom	Refractive	2 years	55	0.10 logMAR (monocular)	Not available	• UCIVA 0.07 logMAR (monocular). • 7% patients reported moderate glare • 5% patients reported moderate halo	Not reported
Cezon (2010)	Rayner M-flex	Refractive	1 year	32	0.28 logMAR (monocular)	0.28 logMAR (monocular)	• UCIVA 0.15 logMAR • CIVA 0.15 logMAR (monocular).	Not reported
Kohnen (2006)	AcrySof ReSTOR MA60D3	Diffractive	6 months	127	0.14 logMAR in 66.9% (binocular)	0.14 logMAR in 71.2% (binocular)	• 84.6% spectacle independence for near • 8.5% patients reported severe glare • 4.2% patients reported severe halo	• 2 eyes implants replacement • 2 eyes with cystoid macular edema • 1 eye flat macular edema • 1 eye macular edema with fibrous reaction • 1 cystic maculopathy
Packer (2010)	Tecnis multifocal	Diffractive	1 year	244	0.20 logMAR (monocular) 0.10 logMAR (binocular)	0.18 logMAR (monocular) 0.10 logMAR (binocular)	• 95.5% spectacle independency for distance • 86.6% spectacle independency for near • 94.6% satisfied • 10.3% patients reported moderate glare • 2.6% patients reported severe glare • 84.8% spectacle independence	• 1 pupilloplasty • 4 IOL explantation • 12.8% eyes required Yag laser
Mojzis (2014)	AT Lisa tri 839MP	Diffractive trifocal	6 months	60	0.20 logMAR (monocular)	0.17 logMAR (monocular)	• UCIVA 0.08 logMAR • DCIVA 0.08 logMAR (monocular)	Not surgical complications
Sheppard (2013)	Finevision trifocal	Diffractive trifocal	2 months	30	Not available	Not available	• UCDVA 0.19 logMAR (monocular) • NAVQ Rasch scores satisfaction at near 15.9 logits	Not reported
Voskresenskaya (2010)	MIOL-Record trifocal	Diffractive trifocal	6 months	36	0.10 logMAR (monocular)	0.10 logMAR (monocular)	• UCIVA, DCIVA 0.2 logMAR, Scotopic • CS 0.2 log unit below standard values at all spatial frequencies • 98% patient's spectacle freedom • 25% patients reported halos	Not surgical complications
Shah (2014)	Lentis Mplus X LS-313	Rotationally asymmetric	3 months	34	0.18 logMAR (monocular)	0.15 logMAR (monocular)	NAVQ Rasch scores satisfaction at near 20.43 logits	Not surgical complications
Venter (2014)	SBL-3	Rotationally asymmetric	3 months	106	0.12 logMAR (monocular); 0.08 logMAR (binocular)	0.11 logMAR (monocular); 0.08 logMAR (binocular);	• UCIVA 0.16 logMAR (monocular) & 0.13 logMAR (binocular) • DCIVA 0.15 logMAR (monocular) & 0.1 logMAR)(binocular) • 94.4% satisfied or very satisfied • 86.8% had no difficulty at all or little difficulty performing tasks that require good close up vision	Not surgical complications
Baikoff (2004)	Anterior pIOL	Refractive	1 year	55	0.23 logMAR (monocular)	Not available	• Efficacy ratio of 80% • Safety ratio of 94%	• Slight pupil ovalization in 10% eyes • Mean endothelium cell loss less than 5% • 4 IOL explantation because dissatisfaction
Alio (2005)	The AMO multifocal phakic IOL prototype	Refractive	1 year	34	0.20 logMAR (binocular)	Not available	• UCIVA 0.00 (binocular) • Steropsis near 80.62 seconds of arc • Patient satisfaction very good in 88% patients	Not surgical complications
Cumming	Crystalens AT-45	Accommodati	1 year FDA	263 eyes	0.20 logMAR	0.20 logMAR	• DCIVA 0.1 in 95% eyes (binocular)	• Endophthalmitis 1 eye

(2006)		ve	clinical trial		or better in 93.5% (binocular)	or better in 83.9% (binocular)	• 25.8% patient's spectacle freedom	• 12 eyes IOL dislocation • 2 eye retinal detachment • 1 eye iridectomy • 1 eyes with persistent corneal edema • 3 eyes with iritis
Sanders (2010)	Tetraflex	Accommodative	1 year FDA clinical study	255	0.4 logMAR in 77%	0.4 logMAR or better in 67%	• 90% could read ≥ 80 wpm at the 0.2 logMAR print size • 75% patients reported never or occasionally wore near glasses	Malpositioning of 5 IOLS
Mastropasqua (2007)	1CU Human Optics	Accommodative	2 years	14	Not available	0.2 logMAR at 6 months 0.48 logMAR at 2 years	AA 1.9D at 6 months and 0.30D at 2 years	Anterior & posterior opacification in 100% of cases
Alio (2009)	The NuLens	Accommodative	1 year	10 (Cataract & atrophic macular degeneration)	Increase of 3.8 Jaeger rows (6 months)	Not available	Cross-section measurement of IOL of 0.09 mm (equivalent to 10D)	• 1 posterior synechia inducing IOL tilt • 1 capsulorhexis edge capture by the haptic ednplate inducing high myopia

*Note: some visual acuities were converted to logMAR using the Visual acuity conversion chart prepared by Jack T Holland

LogMAR: Log Minimum Angle of Resolution
CLE: Clear Lens Extraction
UCNVA: Uncorrected near visual acuity
BDCNVA: Best distance corrected near visual acuity
UCIVA: Uncorrected intermidiate visual acuity
CIVA: Corrected intermidiate visual acuity
DCIVA: Distance corrected intermidiate visual acuity
AA Amplitude of Accommodation
CS: Contrast Sensitivity
HOA: High order aberration

Table 2. Visual results of intraocular lenses