

The Science of Pseudoaccommodation and Its Therapeutic Potential

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Abstract: Pseudoaccommodation is a critical yet often underappreciated factor influencing visual outcomes after cataract surgery. Despite the irreversible loss of true accommodation due to presbyopia or intraocular lens (IOL) implantation, many patients retain meaningful near and intermediate vision—a phenomenon driven by optical and anatomical contributors such as pupil size, astigmatism, and higher-order aberrations. This functional benefit, known as pseudoaccommodation, can be further enhanced pharmacologically through miotic agents like pilocarpine or surgically via multifocal and extended depth-of-field (EDOF) IOLs. However, these strategies may come with trade-offs, including dysphotopsia and reduced contrast sensitivity. Understanding the mechanisms and limitations of pseudoaccommodation is essential for optimizing IOL selection, managing patient expectations, and improving satisfaction. This comprehensive review synthesizes the current evidence on the anatomical, optical, pharmacologic, and technological factors that contribute to pseudoaccommodation, offering practical guidance for counseling both phakic and pseudophakic presbyopic patients.

Keywords: presbyopia, optical system, pseudoaccommodation

Introduction

Presbyopia remains one of the most prevalent causes of near-vision impairment worldwide, affecting virtually all individuals over the age of 40. As the crystalline lens loses its elasticity and the ciliary muscle–zonular complex becomes less effective, true accommodation diminishes, leading to dependence on reading glasses or other corrective strategies. However, many presbyopic and pseudophakic patients still demonstrate a degree of functional near vision that exceeds what would be expected from complete loss of accommodation. This phenomenon—termed pseudoaccommodation—is driven by static optical and anatomical factors such as pupil size, astigmatism, and higher-order aberrations, as well as by newer intraocular lens (IOL) and corneal technologies that extend depth-of-field.

Because pseudoaccommodation blurs the traditional distinction between “accommodating” and “non-accommodating” eyes, it has become a central concept in modern presbyopia management. Multifocal and extended-depth-of-field (EDOF) IOLs, miotic eye drops, and advanced corneal laser procedures all exploit aspects of pseudoaccommodation to reduce spectacle dependence, but the mechanisms, outcomes, and patient suitability vary widely (Figure 1). Understanding these factors is crucial for clinicians selecting the most appropriate intervention and for researchers developing next-generation solutions.

The purpose of this review is to critically examine the evidence on factors influencing pseudoaccommodation in both phakic and pseudophakic presbyopes—including astigmatism, pupil diameter, higher-order aberrations, pharmacological modulation, and modern IOL and corneal designs—and to place these findings within the context of a new functional classification of intraocular lenses based on defocus curves.

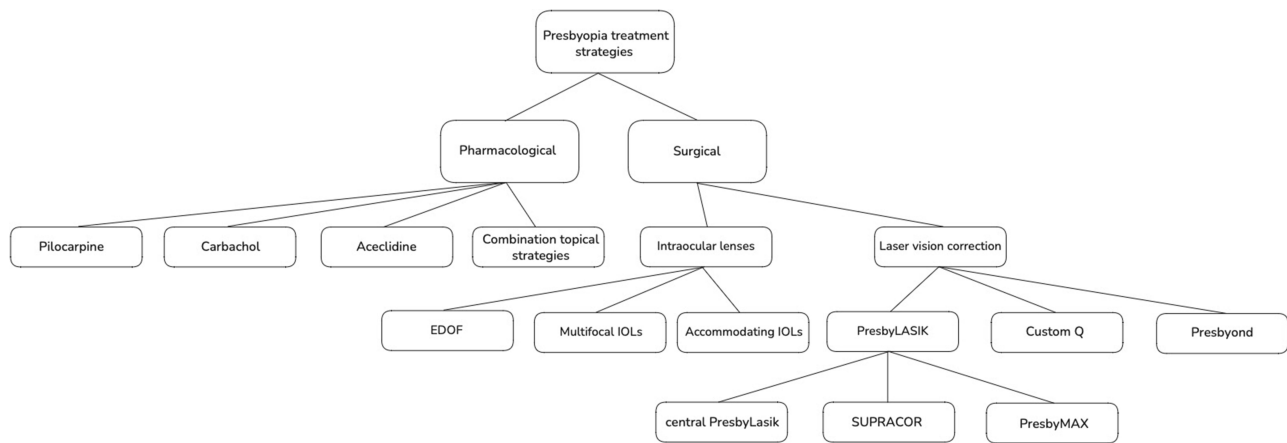


Figure 1 Overview of presbyopia treatment strategies.

What Was Known

Pseudoaccommodation explains residual near vision in presbyopic and pseudophakic eyes; it's influenced by astigmatism, pupil size, and higher-order aberrations.

Multifocal and EDOF IOLs, as well as miotic drops, can enhance near vision but often at the cost of reduced contrast sensitivity or dysphotopsias.

What This Paper Adds

Presents a critical appraisal of current strategies to enhance pseudoaccommodation (IOL design, pharmacological and corneal approaches) in light of emerging evidence.

Frames these findings within the new functional classification of intraocular lenses based on defocus curves, offering a structured perspective for future lens selection and innovation.

Search Strategy and Scope

To identify relevant studies, we searched PubMed/MEDLINE, Embase, and the Cochrane Library from January 1990 through June 2024 using combinations of the terms “pseudoaccommodation,” “presbyopia,” “intraocular lenses,” “pupil size,” “higher-order aberrations,” and “depth of field/focus.” We included English-language original articles, clinical trials, and systematic reviews addressing factors influencing pseudoaccommodation in either phakic or pseudophakic eyes. Reference lists of key papers were hand-searched to identify additional studies. This approach was designed to capture both foundational and the most recent evidence, but it is not intended as a fully systematic review.

(Pseudo)accommodation vs Depth-of-Field vs Depth-of Focus

Accommodation (true accommodation) refers to the dynamic change in the eye's optical power—driven by ciliary muscle contraction—that allows clear vision at different distances.¹ Pseudoaccommodation describes static optical factors such as pupil size, astigmatism, and higher-order aberrations that enhance near vision without active ciliary muscle involvement.² Pseudophakic accommodation denotes a dynamic refractive change produced by anterior movement of the intraocular lens–capsular bag complex in response to ciliary muscle contraction.³ The functional near vision achieved with multifocal intraocular lenses or multifocal corneal procedures is therefore considered pseudoaccommodation. Depth of field (DOFi) refers to the range in object space over which images appear acceptably sharp, whereas depth of focus (DOFo) denotes the tolerance to defocus at the retinal image plane.⁴ Although related, these concepts are distinct and are often used interchangeably in the literature, contributing to ongoing confusion.

Accommodation Mechanism

Accommodation is the process by which the eye's optical power adjusts to facilitate near vision. The most widely accepted theory of accommodation, proposed by Helmholtz, describes this process as involving contraction of the ciliary muscle, relaxation of the zonular fibers, and an increase in the curvature of the crystalline lens.¹ According to this theory, accommodation is lost with age due to a decline in the elasticity of the crystalline lens.⁵ However, as the range of near vision can vary among presbyopic patients, both phakic and pseudophakic, the concept of pseudoaccommodation was introduced.⁶ This term encompasses not only the optical and anatomical features of the eye that increase the depth of field but also advancements in pseudoaccommodative intraocular lenses (IOLs).

Pseudoaccommodation

Diffraction or refractive multifocal IOLs and extended-depth-of-field (EDOF) IOLs, are gaining popularity among ophthalmologists and patients due to their ability to reduce dependence on glasses and significantly improve quality of life.^{7,8} However, these lenses are not without drawbacks. Patients often report reduced contrast sensitivity under low light conditions (mesopic contrast) and positive dysphotopsia.⁹ Additionally, not all patients are suitable candidates for pseudo-accommodative IOLs.

Corneal or macular diseases—such as Fuchs' dystrophy, age-related macular degeneration (AMD), or epiretinal membrane—can impair postoperative visual outcomes and are generally considered contraindications for pseudo-accommodative IOL implantation.¹⁰ Furthermore, patients with high visual quality expectations or occupations requiring high-contrast vision are often deemed unsuitable for multifocal or EDOF IOLs.¹¹

While monofocal IOLs do not enhance accommodation by definition, certain optical and anatomical characteristics, such as astigmatism, pupil size, and corneal aberrations, can improve pseudoaccommodation. Identifying these features during the preoperative assessment is essential.

This review examines the anatomical and optical factors that influence the range of near vision in both phakic and pseudophakic patients.

Measurement of Pseudoaccommodation

Pseudoaccommodation has been investigated in numerous studies using both objective and subjective methods. In subjective methods, it is influenced by factors such as target type, target size, and testing conditions.^{12,13} In phakic eyes, the measurement of pseudoaccommodation requires pharmacologic blockage of the ciliary body. A commonly used subjective method for measuring pseudoaccommodation is the defocus curve. In this test, additional lenses are sequentially superimposed on the distance correction, ranging from +1.50 D to −2.50 D in incremental steps.¹⁴ For each lens addition, distance visual acuity is assessed. Although the criteria for assessing pseudoaccommodation vary among studies, the most commonly used benchmark in pseudophakic eyes is the defocus level corresponding to a visual acuity of 0.20 logMAR.¹⁵

Objective measurements of pseudoaccommodation can be obtained using aberrometers.¹⁶ Wavefront analysis provides optical quality metrics, and the through-focus visual Strehl optical transfer function (VSOTF) has been proposed as a method for evaluating pseudoaccommodation in both phakic and pseudophakic eyes.^{17,18} This method determines the dioptric range at which the image quality parameter declines to a cut-off level, with specific cut-off values varying across studies.

In real-life scenarios, the assessment of pseudoaccommodation is often performed using distance, intermediate, and near vision testing, providing a direct measure of functional improvement.¹⁹ In many studies, this assessment is further complemented by the incorporation of the defocus curve. However, the effectiveness of visual acuity measurements depends on standardized testing conditions.^{20,21} The use of a wide variety of vision charts at different testing distances leads to inconsistencies and makes the results difficult to compare.^{22,23}

Role of Astigmatism in Pseudoaccommodation

Although numerous studies have investigated the role of astigmatism in pseudoaccommodation, a consensus has not yet been reached (Table 1). A theoretical study by Sawusch and Guyton demonstrated that a refraction of −1.0/+0.75 (sphere/

Table 1 Summary of the Effects of Astigmatism on Pseudoaccommodation, Depth of Field and Visual Acuity

Study	Astigmatism (Diopters, mean ± SD, range)	Astigmatism Axis	Amplitude of Pseudoaccommodation (AoP) or Depth of Field (DOFi) (Diopters, mean ±SD)	Visual Acuity (Snellen/ Jaeger)
Yamamoto ²⁵	0.99 ± 0.45 (0.50–2.00)	ATR	AoP 2.40 ± 1.38 (0.52–5.57)	No data
	0.96 ± 0.39 (0.50–2.00)	WTR	AoP 2.86 ± 1.49 (0.36–5.67)	
	0.04 ± 0.09 (<0.50)	Minimal astigmatism all axes	AoP 2.40 ± 1.30 (0.51–6.08)	
Leube ²⁶	0.50	ATR	DOFi 0.95 ± 0.32	No data
			ΔDOFi 0.01	
	0.50	WTR	DOFi 1.14 ± 0.34	
			ΔDOFi 0.20	
Tavazzi ²⁷	0.25–2.00	ATR	DOFi 0.46 ± 0.14	No data
	0.25–2.00	WTR	DOFi 0.56 ± 0.20	
Trindade ²⁸	1.00–1.50	ATR	No data	UDVA 100% ≥0.50
				UNVA 90% J1-J2
	1.00–1.50	WTR	No data	UDVA 100% ≥0.50
				UNVA 80% J5-J6
Bradburry ²⁹	1.00–2.00	WTR	No data	UDVA 82% >0.50
				UNVA >N10
Hillman ³⁰	0.25–2.00	ATR	No data	UDVA 69.2% ≥0.50
				UNVA ≥ N10
	0.25–2.00	WTR	No data	UDVA 61.3% ≥0.50
				UNVA ≥N10
	0.25–2.00	Oblique	No data	61.1% UDVA ≥0.50
				UNVA ≥N10
Datiles ³¹	1.75 ± 0.891	Unspecified	No data	UDVA ≥ 0.50
				UNVA ≥J3
Nanavaty ³²	0.76 ±0.33	ATR	0.85 ±0.52	UDVA ≥0.50
				UNVA ≥J4
Verzella ³³	1.50	ATR	No data	Monocular UDVA 68% ≥0.50
				Monocular UNVA 67% ≥ J3
				Binocular UDVA 84% ≥0.50
				Binocular UNVA 82% ≥ J3
Nagpal ³⁴	<0.50	Any axis	No data	UDVA 47.5% ≥0.80
				UNVA 42.5% ≥ N9
	0.50–2.50	ATR	No data	UDVA 30% ≥0.80
				UNVA 85% ≥ N9

(Continued)

Table 1 (Continued).

Study	Astigmatism (Diopters, mean \pm SD, range)	Astigmatism Axis	Amplitude of Pseudoaccommodation (AoP) or Depth of Field (DOFi) (Diopters, mean \pm SD)	Visual Acuity (Snellen/Jaeger)
	0.50–2.50	WTR	No data	UDVA 12.5% \geq 0.80 UNVA 25% \geq N9
Singh ³⁵	1.00	Not statistically significant difference	No data	UNVA 0.40

Abbreviations: ATR, against-the-rule; WTR, with-the-rule; AoP, amplitude of pseudoaccommodation; DOFi, depth of field; UDVA, uncorrected distance visual acuity; UNVA, uncorrected near visual acuity;

cylinder) provides the best overall visual acuity for both near and distance vision.²⁴ Interestingly, this combination of refractive errors offered better near and distance visual acuity than 0.5 diopter of myopia.

In contrast, Bradbury et al found that patients with myopic astigmatism and no residual spherical error are more likely to achieve functional near and distance vision.²⁹ Other clinical studies have highlighted that a specific type of astigmatism—against-the-rule (ATR) astigmatism enhances depth of field. Verzella, Calossi, and Nanavaty et al reported that ATR astigmatism of less than 1.5 D allows independence from glasses for both near and distance vision.^{32,33}

Additionally, a study on phakic emmetropes by Tsukamoto et al found that accommodation induces significant ATR astigmatism.³⁶ On the other hand, Yamamoto et al observed that while there were no significant differences in pseudoaccommodation between pseudophakic patients with ATR and with-the-rule (WTR) astigmatism, patients with ATR astigmatism exhibited a statistically significant correlation between pupil diameter or higher-order aberrations (HOA) and pseudoaccommodation.²⁵

Contrarily, a randomized controlled trial by Savage et al involving phakic presbyopes did not show any advantage of ATR astigmatism for near vision.³⁷ Similarly, Kamiya et al found no significant effect of astigmatism on pseudoaccommodation.³⁸

Role of Pupil Diameter

Increasing theoretical and clinical evidence indicates that pupil diameter is critical in visual quality. Interestingly, both excessively large and excessively small pupils can degrade the retinal image.^{39–41} Larger pupils increase spherical aberration, while smaller pupils cause light diffraction at the pupil's edge.

The near reflex induces miosis, leading to the hypothesis that a narrower pupil enhances depth of field and supports near vision. This hypothesis has been validated in clinical studies, as summarized in [Table 2](#). However, due to the confounding effects of spherical aberration and the Stiles-Crawford effect, a precise quantitative relationship between pupil diameter, pseudoaccommodation, and visual quality remains elusive.⁴² Tucker and Charman studied external apertures in cycloplegic patients and found that depth of field ranged from 1D with an 8 mm pupil to 3D with a 1 mm pupil.⁴³ Similarly, Charman and Whitefoot observed that depth of field was highest for a 1 mm pupil, decreased up to 5 mm, and then plateaued.⁴⁴

A computational modelling study by Xu et al highlighted the trade-off between the improved depth of field associated with smaller pupils and the image quality degradation caused by diffraction.⁵⁰ Diffraction effects were most significant for pupil sizes under 2 mm, while maximum image quality was achieved with pupil diameters between 2.5 and 4.5 mm.

Additionally, in pseudophakic eyes, depth of field for a given pupil diameter was found to inversely correlate with visual acuity better than Snellen 20/20.⁵¹

Eye Drops

The role of pupillary diameter in increasing depth of field is well established, making pharmacologic constriction of the pupil a promising approach to managing presbyopia. Pilocarpine, a muscarinic receptor agonist, addresses presbyopia through a dual mechanism of action: it stimulates muscarinic receptors in the iris sphincter and ciliary body muscles,

Table 2 Summary of the Effect of Pupil Size on Pseudoaccommodation, Depth of Field and Visual Acuity

Study	Pupil Size (mm)	Amplitude of Pseudoaccommodation (AoP) or Depth of Field (DOFi) (Diopters, mean \pm SD)	Visual Acuity (Snellen/ Jaeger)
Tucker ⁴³	1.0	DOFi 3.0	No data
	8.0	DOFi 1.0	No data
Charman ⁴⁴	1.0	DOFi 3.0	No data
	5.0	DOFi 0.3	No data
Atchison ¹³	2.0	DOFi 0.86 \pm 0.28	No data
	4.0	DOFi 0.59 \pm 0.20	No data
	6.0	DOFi 0.55 \pm 0.20	No data
Marcos ⁴²	2.0	DOFi 0.54	No data
	4.0	DOFi 0.31	No data
	6.0	DOFi 0.21	No data
Campbell ¹²	2.0	DOFi 0.43	No data
	6.0	DOFi 0.21	No data
Ogle ⁴⁵	2.5–8.0	Δ DOFi 0.12 /mm of pupil size	No data
Yamamoto ⁴⁶	1.0– 4.0	AoP 2.60 \pm 0.32	No data
Lim ⁴⁷	<2.6	No data	UNVA \geq J4
Nanavaty ⁴⁸	3.62	No data	UDVA \geq 0.50
			UNVA \geq 0.50
Benard ⁴⁹	3.0	DOFi 2.06	No data
	6.0	DOFi 1.67	No data

Abbreviations: AoP, amplitude of pseudoaccommodation; DOFi, depth of field; UDVA, uncorrected distance visual acuity; UNVA, uncorrected near visual acuity.

inducing miosis to enhance depth of field and promoting ciliary muscle contraction to improve accommodation.⁵² However, chronic use of pilocarpine can lead to side effects that may limit its adoption.⁵³ To mitigate these adverse effects, various formulations have been developed. Non-steroidal anti-inflammatory agents, steroids, and brimonidine have been added to pilocarpine solutions to reduce inflammatory responses or ciliary body contraction.^{54,55} Additionally, sympathomimetics such as naphazoline have been included to decrease conjunctival vasodilation.⁵⁶

Proprietary solutions with reduced side effects have also gained Food and Drug Administration (FDA) approval. Notably, the FDA has recently approved an optimized formulation of pilocarpine eye drops for correcting presbyopia in humans.⁵⁷ Vuity (AGN-190584, Allergan, USA) eye drops, containing 1.25% pilocarpine hydrochloride, demonstrated efficacy in the Gemini 1 and Gemini 2 clinical trials.⁵⁸ These trials showed that 31% of participants aged 40 to 55 achieved an improvement of three or more lines in near visual acuity without losing more than one line of corrected distance visual acuity. Importantly, near vision in GEMINI was assessed under strictly defined mesopic, high-contrast conditions (\approx 3.2–3.5 cd/m²), whereas distance and intermediate visual acuities were tested under standard photopic lighting. Vuity was found to have an acceptable safety and tolerability profile, with the most commonly reported adverse effects being headaches, conjunctival hyperaemia, and difficulty transitioning focus between near and distant objects.⁵⁸

CSF-1 (Qlosi, Orasis Pharmaceuticals, USA) eye drops, containing 0.4% pilocarpine hydrochloride, were also approved by the Food and Drug Administration (FDA) in 2023.⁵⁹ Phase 3 NEAR-1 and NEAR-2 clinical trials showed

that 40.1% of participants in the CSF-1 group achieved an improvement of three or more lines in near visual acuity.⁶⁰ In contrast to GEMINI, the NEAR program reported near vision testing more broadly under mesopic (low-light), high-contrast conditions without specifying an exact luminance level, while distance vision was again assessed under photopic lighting. CSF-1 demonstrated an acceptable safety profile, with most adverse events reported as mild and transient.⁶⁰

Carbachol, a non-selective acetylcholine receptor agonist, has been investigated in combination with brimonidine. Studies by Abdelkader et al found this combination to be effective.^{61,62} Brimochol PF (Visus Therapeutics, USA), containing 2.25% carbachol and 0.1% brimonidine, completed its first phase 3 clinical trial, BRIO-I.⁶³ The primary endpoint—achieving at least a three-line improvement in near visual acuity—was met by 49.4% of participants. The most common adverse effects were eye irritation and headache.⁶³

Aceclidine is a selective muscarinic agonist that produces pupil miosis and improves depth of focus with minimal ciliary stimulation. In the Phase 3 CLARITY 1 and 2 trials, the lead formulation LNZ100 (1.75% aceclidine) achieved the primary endpoint, with 71% of participants demonstrating a ≥ 3 -line improvement in near visual acuity at 3 hours post-dose, and sustained effect up to 10 hours.⁶⁴ LNZ101 (aceclidine with brimonidine) showed similar efficacy but no superiority. Based on these results, LNZ100 was selected as the lead candidate and subsequently received FDA approval in 2025 for the treatment of presbyopia.⁶⁵

Higher-Order Aberrations

Various studies have explored the role of high-order aberrations (HOAs), particularly spherical aberration, in pseudoaccommodation, as summarized in Table 3. The findings of some studies appear contradictory, which can be attributed to the frequent mixing of two distinct representations of spherical aberration: longitudinal spherical aberration and the Zernike representation of spherical aberration ($Z(4,0)$).⁶⁶

For longitudinal spherical aberration, an optical system with positive spherical aberration focuses peripheral rays in front of paraxial rays, while negative spherical aberration results in the opposite behavior. In contrast, the Zernike representation shows that positive spherical aberration causes a hyperopic defocus of paraxial rays, with peripheral rays focusing in front of them. Therefore, the interpretation of research findings must align with the specific representation of spherical aberration used in the study.

Given these considerations, it is unsurprising that Rocha et al demonstrated that inducing positive or negative spherical aberration using adaptive optics can enhance the depth of field and pseudoaccommodation range by up to 2 diopters.⁶⁷ Similarly, recent research on a novel monofocal IOL designed to induce positive Zernike spherical aberration found that negative Zernike spherical aberration is not the only way to increase the depth of field.⁷⁵

However, to optimize pseudoaccommodation in an optical system using an IOL that induces positive Zernike spherical aberration, the refractive target for IOL implantation should be slightly myopic.⁷⁵

Furthermore, Nanavaty et al analyzed the depth of field in patients after implantation of aspheric and spherical IOLs and found that reducing total spherical aberration might decrease the depth of field.⁷⁶

Notably, Nishi et al reported that vertical coma, rather than spherical aberration, correlates more strongly with pseudoaccommodation.⁷⁰ Despite this, current surgical methods for presbyopia correction often rely on the induction of spherical aberration. Aspheric ablation profiles are commonly employed in laser refractive surgery for presbyopia treatment. Additionally, extended depth of field IOLs—such as the MiniWell (Sifi, Italy), Lucidis (Swiss Advanced Vision, Switzerland) and LuxSmart (Bausch and Lomb) utilize the induction of spherical aberration within the optical system of the eye.⁷⁷

Finally, Hickenbotham et al observed that while spherical aberration can increase the depth of field, it also reduces distance-corrected visual acuity.⁷⁸ It is important to note that spherical aberration levels exceeding $0.56\mu\text{m}$ can significantly degrade image quality and should be carefully managed during surgical interventions.⁷⁹

Limitations of Studies on Factors Affecting Pseudoaccommodation

Research exploring the impact of pupil size, higher-order aberrations, and astigmatism on pseudoaccommodation faces several important limitations. First, most studies are cross-sectional or small in sample size, limiting the ability to infer causality or generalize results. Second, methodological heterogeneity—including non-standardized lighting conditions,

Table 3 Summary of the Effects of High Order Aberrations on Pseudoaccommodation, Depth of Field and Visual Acuity

Study	High Order Aberrations (HOA) (μm , mean \pm SD)	Amplitude of Pseudoaccommodation (AoP) or Depth of Field (DOFi) (Diopters, mean \pm SD)	Pupil Size (mm)	Visual Acuity (Snellen)
Rocha ⁶⁷	Z(4,0) \pm 0.6	DOFi 2.0	6.0	No data
Legras ⁶⁸	Z(4,0) 0.3	DOFi 1.96 \pm 0.12 Δ DOFi 0.11	6.0	No data
	Z(4,0) 0.6	DOFi 2.06 \pm 0.12 Δ DOFi 0.26		
	Z(3,-1) 0.3	DOFi 1.68 \pm 0.20 Δ DOFi -0.18		
	Z(3,-1) 0.6	DOFi 2.16 \pm 0.13 Δ DOFi 0.31		
Zheleznyak ⁶⁹	Z(4,0) 0.2	DOFi 2.19 \pm 0.40 Δ DOFi 0.54	4.0	No data
	Z(4,0) -0.2	DOFi 1.70 \pm 0.14 Δ DOFi 0.05		
Nishi ⁷⁰	Z(3,-1) -0.06 \pm 0.20 (r = 0.311)	AoP 0.51 \pm 0.50	4.0	No data
	Z(4,0) 0.11 \pm 0.07 (r = -0.365)			
Yi ⁷¹	Z(4,0) \pm 0.6	Δ DOFi 0.80	6.0	No data
	Z(6,0) 0.25	Δ DOFi 0.87		
	Z(6,0) -0.25	Δ DOFi 0.70		
Benard ⁴⁹	Z(4,0) -0.6	Δ DOFi 0.85	6.0	No data
	Z(4,0) -0.6 and Z(6,0) 0.1	Δ DOFi 1.20	6.0	
	Z(4,0) -0.6	Δ DOFi 0.31	3.0	
Oshika ⁷²	Z(3,1) and Z(3,-1) and Z(5,1) and Z(5,-1) 0.241 \pm 0.165 (r = 0.440)	AoP 2.03 \pm 0.93	3.51 \pm 0.57	No data
Benard ⁷³	Z(4,0) 0.4	Δ DOFi 0.56	6.0	No data
	Z(4,0) 0.6	Δ DOFi 0.83		
	Z(4,0) -0.3 and Z(6,0) +0.15	Δ DOFi 1.53		
	Z(4,0) -0.6 and Z(6,0) 0.3	Δ DOFi 4.78		
Song ⁷⁴	Z(3,-1) -0.038 \pm 0.043	No data	4.0	DCNVA \geq 0.40

Abbreviations: HOA, high order aberrations; AoP, amplitude of accommodation; DOFi, depth of field; r, Pearson correlation coefficient; DCNVA, distance corrected near visual acuity.

inconsistent visual acuity cut-offs, and variable definitions of pseudoaccommodation—reduces comparability across studies. Third, many investigations rely on subjective testing methods, such as defocus curves or near vision charts, which are influenced by target type, testing distance, and patient cooperation. Together, these limitations highlight the need for standardized, prospective, and adequately powered studies to clarify the role of optical and anatomical factors in pseudoaccommodation.

Intraocular Lenses – Quest for Restoring of Accommodation

It has been suggested that pseudoaccommodation following the implantation of a monofocal IOL may be influenced by the forward movement of the IOL during accommodative effort. Several studies have investigated changes in IOL position during near fixation or after drug-induced ciliary body contraction. For example, Kriechbaum et al found that pilocarpine induces a more pronounced forward movement of the lens, potentially overestimating pseudophakic accommodation compared to measurements taken during near fixation.⁸⁰ Similarly, Marchini et al, using high-frequency ultrasound, observed significant anterior movement of the IOL in response to accommodative stimuli.⁸¹ Findl et al, utilizing partial coherence interferometry (PCI) biometry, reported that forward movement of the IOL could result in an accommodative response of up to 1 diopter (D).⁸²

Other studies have explored how the design of monofocal IOL affects the extent of anterior movement. Vamosi et al compared the single-piece Akreos Disc IOL with the three-piece Acrysof MA60MB during near vision fixation, finding that the three-piece lens demonstrated greater accommodative movement.⁸³ This observation was attributed to the 10-degree optic-haptic angulation in the three-piece IOL. Cleary et al compared the bag-in-the-lens IOL with a standard monofocal IOL and found no significant differences in forward movement during near fixation or pilocarpine stimulation.⁸⁴

These findings have motivated the development of shape-changing IOLs designed to provide functional near visual acuity for pseudophakic patients. Examples include the 1CU (HumanOptics AG, Erlangen, Germany), Tetraflex KH3500 (Lenstec, FL, USA), Crystalens AT-45 (Bausch and Lomb, NY, USA), and Crystalens HD (Bausch and Lomb, NY, USA).⁸⁵ While patients initially demonstrated accommodation of up to 2 D following implantation of these lenses, this effect diminished over time, likely due to fibrosis of the capsular bag.⁸⁶ Additionally, some studies reported high rates of posterior capsule opacification with these lenses.⁸⁷

Intraocular Lenses – Current Perspective

Ribeiro et al has proposed recently a novel functional classification of IOLs based primarily on their defocus curves which is a measure of their range of pseudoaccommodation.⁸⁸ The intraocular lenses were divided into the partial range of field IOLs and the full range of field IOLs. The primary difference lies in their defocus curve performance at the level of visual acuity of 0.2 logMAR. The former have less than 2.3 D of defocus and the latter at least 2.3D of defocus. Furthermore, the partial range of field IOLs are divided into narrow <1.2D, enhance ≥ 1.2 and <1.58, and extend ≥ 1.58 and <2.3). Standardized functional categories—such as those based on defocus curves—compel evaluation of IOLs according to specific, objective criteria. This, in turn, allows meaningful comparison between lenses from different manufacturers, facilitates evidence-based selection of IOLs for individual patients, and improves preoperative counseling by setting realistic expectations regarding near, intermediate, and distance vision outcomes.

Partial Range-of-Field IOLs

Monofocal IOLs

Monofocal lenses differ in their optical properties, particularly in the spherical aberration they introduce to the optical system. In a virgin eye, positive spherical aberration from the cornea is neutralized by negative aberration from the lens.⁸⁹ After cataract removal and implantation of a spherical monofocal IOL, the optical system is predominantly influenced by the positive spherical aberration of the cornea.⁹⁰ Evidence suggests that implanting a monofocal IOL with negative spherical aberration to counteract corneal aberrations can improve night vision. For example, Yagci et al demonstrated that aspheric IOLs enhance photopic visual quality, while Raina et al showed that they improve contrast sensitivity in pediatric eyes.^{91,92} A meta-analysis comparing aspheric and spherical IOLs concluded that spherical lenses may reduce overall visual quality.⁹³

However, the impact of these differences on pseudoaccommodation remains unclear. It has been proposed that aspheric IOLs might decrease, increase, or have no effect on pseudoaccommodation compared to spherical IOLs. Kozhaya et al recently utilized a wavefront simulator and found that positive spherical aberration, unlike negative spherical aberration, do not enhance pseudoaccommodation.⁹⁴ This finding contrasts with some in vivo studies, which

reported improved near vision after spherical IOL implantation.⁹⁵ However, these studies often fail to control for pupil size during near vision assessment and pupil size might have a greater influence on near vision than spherical aberration.⁹⁶ This is supported by Nanavaty et al who compared the aspheric Acri.Smart 36A IOL with the spherically neutral Akreos MI60 IOL and observed that the spherical IOL produced a smaller depth of field.⁹⁷

Enhanced Monofocal IOLs

Recent advancements in the field include enhanced monofocal IOLs which are based either on the principle of additional spherical aberration (RayONE EMV, Rayner, UK), adjusted curvature to allow for increased refraction in the center of the lens (Tecnis Eyhance, Johnson and Johnson, USA; Vivinex Impress, Hoya, Japan) or polynomial surface design (Isopure, BVI Medical, USA).⁹⁸ These lenses are designed to improve intermediate vision without impairment of quality of distance vision. Their defocus curve performance at the level of visual acuity of 0.2 logMAR is ≥ 1.2 and < 1.58 . Table 4 presents summary of visual outcomes of enhanced monofocal IOLs.

Extended Depth-of-Field Lenses

Initially, EDOF lenses were referred to as extended depth of focus lenses. However, it is crucial to note that these lenses extend the depth of field, as the term “field” in optics refers to the object plane. Compared to monofocal IOL, EDOF lenses have a narrower depth of focus. This limitation occurs because EDOF lenses do not concentrate all light energy into a single focal point, making them more susceptible to small position-related dysphotopsias and reductions in visual quality.⁴

The American Academy of Ophthalmology defines EDOF lenses as those providing a depth of field at least 0.5 diopter greater than that of a monofocal lens at a visual acuity of 0.2 logMAR. Furthermore, at least 50% of eyes implanted with an EDOF lens must achieve a distance-corrected intermediate visual acuity (DCIVA) of 0.2 logMAR or better. Additionally, the mean DCIVA at 67 cm must exceed that achieved with a monofocal lens control. Recently, Ribeiro et al introduced a classification system for IOLs, redefining EDOF lenses as extended range of field (EROF) lenses. According to this classification, such lenses must deliver a visual acuity of at least 0.2 logMAR with a defocus range between ≥ 1.58 D and < 2.3 D.⁸⁸

Various optical principles are utilized in designing EDOF lenses. Common approaches include diffraction, refraction, the pinhole effect, the induction of spherical aberration, or wavefront modulation to extend the depth of field. Examples of diffractive EDOF lenses include the Symphony (Johnson & Johnson, USA) and AT LARA (Zeiss, Germany). Lenses utilizing spherical aberration include Lucidis and Mini-Well, while the Vivity lens employs wavefront modulation.¹⁰³ The latest developments also feature purely refractive EDOF designs, such as the Puresee (Tecnis, USA).¹⁰⁴

In terms of depth of field and visual quality, EDOF lenses occupy a middle ground between monofocal and multifocal IOLs (Table 5). Compared to monofocal IOLs, EDOF lenses reduce the need for glasses but offer inferior near vision performance compared to multifocal IOLs.⁷ Although studies indicate that EDOF lenses provide lower overall visual quality than monofocal lenses, they are associated with fewer undesirable visual phenomena, such as glare and halos, compared to multifocal IOLs.^{105,106}

Full Range of Field IOLs

Ribeiro et al classify an IOL as having a full range of field if it achieves a defocus curve of 2.3D or greater for visual acuity of 0.2 logMAR.⁸⁸ This category includes trifocal and bifocal lenses with both low and high add powers.

Bifocal and multifocal IOLs were developed to provide pseudophakic patients with independence from glasses for near vision, as well as for near and intermediate vision, respectively. A recent study comparing the trifocal PanOptix (Alcon, USA) with the monofocal IOL SA60AT (Alcon, USA) found that 80% of patients in the multifocal group never required reading glasses, compared to only 8% in the monofocal group.¹²⁷ Table 5 provides summary of visual acuity outcomes for multifocal IOLs.

The most popular technical solutions in bifocal and multifocal lenses include diffractive echelette designs, which split light into multiple foci. An alternative approach is the introduction of symmetric or asymmetric refractive surfaces with different focal lengths.⁸ Examples of diffractive lenses include the PanOptix (Alcon, USA), AT LISA (Zeiss, Germany),

Table 4 Summary of Visual Acuity Outcomes with Enhanced Monofocal Intraocular Lenses

IOL	IOL Type	Study	UDVA (logMAR, mean ± SD)		DCVA (logMAR, mean ± SD)		UIVA (logMAR, mean ± SD)		DCIVA (logMAR, mean ± SD)		UNVA (logMAR, mean ± SD)		DCNVA (logMAR, mean ± SD)	
			Bino	Mono	Bino	Mono	Bino	Mono	Bino	Mono	Bino	Mono	Bino	Mono
Eyhance Johnson & Johnson	Enhanced monofocal	Giglio ⁹⁹	-0.03 ± 0.07	-	-0.07 ± 0.05	-	0.17 ± 0.12	-	0.13 ± 0.11	-	-	-	-	-
		Auffarth ¹⁰⁰	0.03 ± 0.12	-	-0.06 ± 0.09	-	0.07 ± 0.12	-	0.09 ± 0.11	-	-	-	-	-
Isopure Physiol	Enhanced monofocal	Ang ¹⁰¹	0.00 ± 0.07	-	-0.05 ± 0.07	-	0.10 ± 0.12	-	0.11 ± 0.11	-	-	-	-	-
		Mencucci ¹⁰²	-	0.04 ± 0.05	-	0.02 ± 0.04	-	0.23 ± 0.12	-	0.21 ± 0.09	-	0.44 ± 0.11	-	0.32 ± 0.09
Rayone EMV Rayner	Enhanced monofocal	Garcia-Bella ⁷⁵	0.01 ± 0.08	0.06 ± 0.11	-0.07 ± 0.05	-0.03 ± 0.06	0.13 ± 0.07	0.19 ± 0.09	0.24 ± 0.09	0.28 ± 0.07	-	-	-	-

Abbreviations: IOL, intraocular lens; UDVA, uncorrected distance visual acuity; UIVA, uncorrected intermediate visual acuity; UNVA, uncorrected near visual acuity; DCVA, distance corrected visual acuity; DCIVA, distance corrected intermediate visual acuity; DCNVA, distance corrected near visual acuity; Bino, binocular; Mono, monocular.

Table 5 Summary of Visual Acuity Outcomes with Extended Depth-of-Field and Multifocal IOLs

IOL	IOL Type	Study	UDVA (logMAR, mean ± SD)		DCVA (logMAR, mean ± SD)		UIVA (logMAR, mean ± SD)		DCIVA (logMAR, mean ± SD)		UNVA (logMAR, mean ± SD)		DCNVA (logMAR, mean ± SD)	
			Bino	Mono	Bino	Mono	Bino	Mono	Bino	Mono	Bino	Mono	Bino	Mono
Acrysof IQ Vivity Alcon	EDOF	Shafer ¹⁰⁷	0.07 ± 0.12	-	-0.01 ± 0.09	-	0.18 ± 0.18	-	0.11 ± 0.12	-	0.30 ± 0.20	-	0.30 ± 0.15	-
		Pantanelli ¹⁰⁸	0.02 ± 0.13	-	-0.01 ± 0.10	-	0.01 ± 0.14	-	0.02 ± 0.13	-	-0.03 ± 0.14	-	0.03 ± 0.12	-
LuxSmart Bausch&Lomb	EDOF	Campos ¹⁰⁹	0.02 ± 0.11	0.10 ± 0.11	-	-	0.18 ± 0.12	0.21 ± 0.08	-	-	0.38 ± 0.14	-	-	-
		Tahmaz ¹¹⁰	-	0.09 ± 0.15	-	0.00 ± 0.05	-	0.17 ± 0.19	-	0.18 ± 0.16	-	-	-	-
Mini Well Ready Sifi Medtech	EDOF	Auffarth ¹¹¹	-	0.06 ± 0.15	-	-0.05 ± 0.11	-	0.09 ± 0.11	-	0.06 ± 0.12	-	0.18 ± 0.14	-	0.18 ± 0.14
		Savini ¹¹²	-	-	0.00 ± 0.05	0.02 ± 0.07	-	-	-	-	-	-	0.26 ± 0.13	0.39 ± 0.16
IC-8 Acufocus	EDOF	Dick ¹¹³	-	0.06 ± 0.15	-	-0.02 ± 0.12	-	0.08 ± 0.12	-	0.10 ± 0.11	-	0.18 ± 0.14	-	0.25 ± 0.14
		Hooshmand ¹¹⁴	0.13 ± 0.16	-	-	-	-	0.10 ± 0.19	-	-	-	0.18 ± 0.17	-	-
Synthesis Plus Cutting Edge	EDOF	Iradier ¹¹⁵	-	0.11 ± 0.17	-	0.04 ± 0.11	-	-	-	-	-	0.14 ± 0.22	-	0.37 ± 0.36
Lucidis Swiss Advanced Vision	EDOF	Rabinovich ¹¹⁶	0.038 ± 0.05	-	-	-	0.09 ± 0.1	-	-	-	0.16 ± 0.14	-	-	-
		Pedrotti ¹¹⁷	0.02 ± 0.16	-	-0.07 ± 0.09	-0.04 ± 0.08	-	-	0.04 ± 0.09	0.11 ± 0.11	-	-	0.00 ± 0.08	0.07 ± 0.11
Tecnis Symphony Johnson & Johnson Vision	EDOF	Chang ¹¹⁸	0.03	-	-0.05	-	0.00	-	0.03	-	0.15	-	0.23	-
		Reinhard ¹¹⁹	0.02 ± 0.16	0.12 ± 0.19	-0.03 ± 0.13	0.05 ± 0.16	0.11 ± 0.14	0.20 ± 0.18	0.08 ± 0.14	0.18 ± 0.17	0.30 ± 0.17	0.39 ± 0.20	0.30 ± 0.18	0.39 ± 0.21
AT LARA 829MP Zeiss	EDOF	Reinhard ¹¹⁹	0.02	0.12 ± 0.18	-0.03	0.05 ± 0.16	0.07	0.16 ± 0.17	0.05	0.12 ± 0.18	0.23	0.34 ± 0.22	0.22	0.32 ± 0.19
AT LISA Tri 839MP Zeiss	MFIOL	Bilbao – Calabuig ¹²⁰	-0.01 ± 0.06	-	-	-	-0.05 ± 0.08	-	-	-	0.05 ± 0.08	-	-	-
		Mendicutie ¹²¹	0.03 ± 0.09	-	-	-	0.10 ± 0.15	-	-	-	0.15 ± 0.14	-	-	-
FineVision Micro F Physiol	MFIOL	Bilbao – Calabuig ¹²⁰	0.01 ± 0.05	-	-	-	-0.05 ± 0.12	-	-	-	0.05 ± 0.08	-	-	-
		Cochener ¹²²	0.01 ± 0.07	0.01 ± 0.06	-	-	-	0.08 ± 0.10	-	-	-0.03 ± 0.04	0.00 ± 0.04	-	-
Finevision Pod F Physiol	MFIOL	Poyales ¹²³	-	-	-0.04 ± 0.04	-	-	-	0.09 ± 0.10	-	-	-	0.10 ± 0.09	-
Acrysof IQ Panoptix Alcon	MFIOL	Alio ¹²⁴	0.07 ± 0.10	-	0.01 ± 0.04	-	0.12 ± 0.13	-	0.12 ± 0.12	-	0.16 ± 0.09	-	0.13 ± 0.08	-
		Monaco ¹⁰⁶	-	0.00 ± 0.04	-	-0.01 ± 0.01	-	0.23 ± 0.07	-	0.13 ± 0.07	-	0.02 ± 0.06	-	0.01 ± 0.04
Tecnis Synergy Johnson & Johnson Vision	MFIOL	Chang ¹²⁵	-	-	-0.056 ± 0.087	-	-	-	-	-	-	-	0.047 ±0.124	-
		Ferreira ¹²⁶	-	-	-0.04 ± 0.08	-0.01 ± 0.08	-	-	-0.01 ± 0.10	0.04 ± 0.11	-	-	-0.01 ± 0.08	0.01 ± 0.08

Abbreviations: EDOF, extended depth of field; MFIOL, multifocal intraocular lens; UDVA, uncorrected distance visual acuity; UIVA, uncorrected intermediate visual acuity; UNVA, uncorrected near visual acuity; DCVA, distance corrected visual acuity; DCIVA, distance corrected intermediate visual acuity; DCNVA, distance corrected near visual acuity; Bino, binocular; Mono, monocular.

and FineVision (Physiol, Belgium), while refractive designs are represented by lenses such as the Lentis MPlus (Teleon Surgical).¹²⁸

While multifocal and bifocal IOLs provide functional near vision, studies indicate that their implantation is associated with positive dysphotopsias, such as glare and halos.^{129,130} These effects make such lenses less suitable for patients who require high-quality vision, such as professional drivers. Although 30–60% of patients report dysphotopsias after multifocal IOL implantation these symptoms typically diminish over time, with only about 5% of patients finding them bothersome six months post-surgery.¹²⁷

Principles of Laser Vision Correction

Various laser vision correction techniques have been developed to address pseudoaccommodation and presbyopia. Similar to concepts in IOL design, dedicated ablation profiles have been created to enhance depth of field. These laser procedures can be categorized into three main groups: PresbyLASIK, Custom-Q, and Presbyond.¹³¹

The term PresbyLASIK encompasses various corneal-based treatments for presbyopia, including the AMO VISX presbyopia-correcting profile (AMO Development LLC, Milpitas, CA, USA), SUPRACOR (Technolas Perfect Vision GmbH, Munich, Germany), and PresbyMAX (Schwind eye-tech-solutions, Kleinostheim, Germany).

The PresbyMAX technique is further divided into three subtypes: symmetric, micro-monovision, and hybrid.¹³² PresbyMAX symmetric creates a biaspheric cornea, with a central zone targeting -1.9D and a peripheral zone targeting -0.4D .¹³³ PresbyMAX micro-monovision involves setting different refractive targets for the dominant and non-dominant eyes, such as $0\text{D}/-1.5\text{D}$ for the dominant eye and $-0.8\text{D}/-2.3\text{D}$ for the non-dominant eye.¹³² PresbyMAX hybrid resembles micro-monovision but targets a lower degree of myopia in the dominant eye, aiming for -0.1D and -0.9D in the peripheral and central zones, respectively.¹³⁴ All these techniques aim to create corneal multifocality, with the central area optimized for near vision and the peripheral area for distance vision.

Supracor produces multifocal corneal profile by creating a central elevation of approximately $12\ \mu\text{m}$ within the central 3-mm zone to provide a near addition of about 1.75 D.¹³⁵ This is surrounded by an aberration-optimized transition zone designed to preserve intermediate and distance vision. Distance correction is performed according to the baseline ametropia, with a target refraction of emmetropia or -0.50D .

Custom-Q (Alcon Laboratories, Inc., Fort Worth, TX, USA) focuses on inducing a hyperprolate cornea in the non-dominant eye, which adds negative spherical aberration. Combined with a refractive target of -0.5D in the non-dominant eye and a distance-corrected dominant eye, this approach improves depth of field.^{136,137}

Finally, Laser Blended Vision (LBV), originally developed by Dan Reinstein, integrates micromonovision (-1.5D in the non-dominant eye), the induction of spherical aberration, and neuroadaptation to extend depth of field.¹³⁸ Studies indicate that Presbyond, an example of LBV, induces negative spherical aberration (Zernike coefficient (4,0)) to achieve this extended depth of field.^{138,139}

Clinical Outcomes of Laser Vision Correction

PresbyLASIK

Uthoff et al assessed PresbyMAX symmetric (target $+1.5\text{D}$) in presbyopes with hyperopia, emmetropia, or myopia.¹⁴⁰ Overall, 83% could read standard newspaper print and UNVA better than 0.3 LogRAD was seen in 90% of emmetropes and 80% of hyperopes and myopes. UDVA of 0.1 LogMAR or better was achieved by 83% overall (100% hyperopes, 80% emmetropes, 70% myopes). CDVA loss ≥ 1 line occurred in 50% of hyperopes and emmetropes and 30% of myopes.

Baudu et al conducted one of the largest investigations of PresbyMAX symmetric, enrolling 358 presbyopic patients presenting with either myopia or hyperopia.¹³³ At six months postoperatively, binocular uncorrected distance visual acuity (UDVA) better than 20/25 was achieved in 70% of the myopic cohort and 74% of the hyperopic cohort, while uncorrected near visual acuity (UNVA) of J3 or better was attained by 94% and 87% of patients, respectively. The authors also reported a retreatment rate of 19% in both groups.

PresbyMAX hybrid produced superior outcomes compared with PresbyMAX symmetric in the study by Luger et al^{134,141} At one year, 93% of patients achieved binocular UDVA of 20/20 or better. In subgroup analysis, 100% of myopes attained UDVA of 20/25 or better, while 94% of hyperopes achieved UDVA of 20/20 or better. Binocular UNVA

of J2 or better was observed in 93% of myopes and 88% of hyperopes. Loss of ≥ 2 lines of CDVA occurred in 7% of myopes and 6% of hyperopes. Retreatment was required in 19% of cases and 3% underwent reversal of the treatment; after retreatment all patients achieved UDVA of 20/25 or better.

Ang et al evaluated Supracor in 69 hyperopic eyes of 58 patients, divided into three groups: bilateral Supracor, Supracor with contralateral hyperopic LASIK, and Supracor with no treatment in the fellow eye.¹³⁵ Across all groups, 100% achieved binocular UDVA better than 20/25 and 93% UNVA of J2 or better, with no significant intergroup differences.

Pajic et al investigated Supracor with micro-monovision in myopic presbyopes and reported favorable outcomes at 6 months: 86% achieved UDVA of 20/20, 92% attained UNVA of 20/20, and 78% reached UNVA of 20/20. UNVA of 20/20 was seen in 36% of dominant and 64% of nondominant eyes, results comparable to those reported in hyperopic presbyopes.¹⁴²

Jackson et al reported the study using the AMO VISX platform for central presbyLASIK, conducted in hyperopic presbyopes.¹⁴³ At 1 year, all 25 patients achieved binocular UDVA of 20/25 or better and UNVA of J3 or better, while a loss of two lines of CDVA was observed in 10%.

Custom Q

Yin et al evaluated 138 hyperopic presbyopes and reported 1-year outcomes.¹⁴⁴ Patients with a ΔQ of -0.8 achieved binocular UDVA of 20/16 and UNVA of J2. Overall, 100% attained UDVA of 20/25 or better and UNVA of J3 or better; however, 6% lost one line of CDVA and 13% required retreatment. Similarly, Courtin et al studied 65 patients and found 91% achieved UDVA of 20/20 or better and 81% UNVA of J3 or better.

Presbyond

Reinstein et al studied Presbyond in hyperopic, emmetropic, and myopic presbyopes.^{138,145,146} In hyperopes, 86% achieved CDVA of 20/20 and all had binocular CDVA $\geq 20/40$, 81% read J2 and all reached at least J5. No patient lost ≥ 2 CDVA lines, however 22% required retreatment. Among emmetropes, 95% achieved UDVA of 20/20 and 96% UNVA of J2 or better, with no ≥ 2 -line CDVA loss. Myopic patients achieved binocular UDVA of 20/20, with 99% attaining UNVA of J5 or better and 96% J2 or better.

Conclusions

In conclusion, modern approaches to presbyopia correction combine optical, pharmacological, and surgical strategies to enhance near vision and depth of field. Most current interventions—such as advanced intraocular lenses, miotic eye drops, and corneal or laser procedures—exploit the principles of pseudoaccommodation, although their mechanisms and outcomes differ. While these approaches can reduce spectacle dependence and improve functional vision, limitations such as dysphotopsia, reduced contrast sensitivity, and variability in patient selection remain key challenges for future research.

Disclosure

The authors report no conflicts of interest in this work.

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