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# Spiral optics in intraocular lenses – a new paradigm in the pursuit of continuous vision after cataract surgery

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**HIGHLIGHTS**

Cataract surgery is becoming refractive. Multifocal and EDOF IOLs have limits. Spiral optics offers continuous vision with fewer halos. Early results are promising.

## ABSTRACT

Age-related cataract is a leading cause of visual impairment due to progressive changes in the crystalline lens. Modern cataract surgery has evolved into a refractive procedure aimed at restoring high-quality vision at multiple distances. Advanced intraocular lenses, including multifocal and EDOF (extended depth-of-focus) designs, address these needs but may cause photic phenomena and reduced contrast sensitivity. Spiral optics is a novel approach based on continuous phase modulation, offering an extended range of vision with fewer optical side effects. Early studies show promising visual outcomes, though further research is needed to confirm long-term safety and efficacy.

**Key words:** age-related cataract, intraocular lenses, EDOF, multifocal lenses, spiral optics, refractive surgery, photic phenomena

## INTRODUCTION

Age-related cataract develops as a consequence of physiological ageing processes that lead to progressive opacification of the crystalline lens. With age, lens proteins undergo denaturation and aggregation, resulting in decreased protein solubility and the formation of insoluble light-scattering aggregates. The lens also becomes thicker and less elastic, while progressive yellowing and changes in its optical properties contribute to deterioration of visual quality, affecting both distance and near vision.

Cataract surgery is performed to restore visual function compromised by these structural and optical changes in the crystalline lens. In recent years, cataract surgery has increasingly evolved into a refractive procedure aimed at providing high-quality vision across all distances. Patients today no longer expect only improved distance vision; they increasingly seek spectacle independence and high-quality vision at far, intermediate, and near distances, enabling them to perform everyday activities –from using digital devices to reading fine print – without spectacles.

## INTRAOCULAR LENSES

To meet rising patient expectations, modern intraocular lenses (IOLs), including multifocal designs and extended depth-of-focus (EDOF) lenses, have been developed to improve visual performance over a broad range of distances. Their characteristics are summarized in table 1 [1]. Numerous studies have shown that trifocal IOLs in particular can provide excellent functional outcomes and high patient satisfaction, especially after bilateral implantation, while supporting distance, intermediate, and near vision. Despite these advantages, conventional diffractive trifocal IOLs have important limitations [2–4]. They work by splitting incoming light among several focal points. Although this extends the range of vision, some light energy is lost and interference effects arise, potentially reducing contrast sensitivity and producing glare and halos. These effects have been demonstrated in clinical studies, psychophysical simulations, and virtual-implantation models that can predict visual quality before surgery [4]. Under low-light conditions, they may substantially affect everyday functioning, for example by making night driving or reading in dim light more difficult.

Intermediate vision remains an additional challenge. Although trifocal IOLs provide good visual acuity at specific focal points, distributing light among these foci may produce comparatively poorer performance at intermediate distances, such as during computer work. By contrast, EDOF lenses use a more continuous optical profile, providing smoother transitions between distances, with fewer halos and less glare; however, they often do not deliver near vision of the same quality as multifocal designs [5, 6]. This limitation may be noticeable during tasks that require high visual precision, such as reading small print or performing fine manual work.

Contemporary IOL design increasingly incorporates advanced simulation tools, including virtual IOL implantation systems, which make it possible to assess potential visual outcomes and tailor the implant more closely to the individual patient's needs [7].

## SPIRAL OPTICS

Spiral optics represents a new approach to IOL design in which the conventional division of light into several discrete foci is replaced by continuous phase modulation in a spiral configuration. This design creates an elongated focal region along the optical axis, producing a continuous range of vision from distance to near while maintaining relatively stable image quality. Unlike diffractive multifocal IOLs, spiral optics does not rely on distributing light energy among

TABLE 1

Summary of the characteristics of intraocular lenses [1].

| IOL type | SA/optical design | Range of focus | Target refraction: dominant eye | Target refraction: nondominant eye | Clinical considerations |
|---|---|---|---|---|---|
| Monofocal (aspheric) | Neutral/corneal SA-compensating | Single focus (distance) | Plano to +0.25 D | -1.25 to -2.00 D (monovision) or plano to +0.25 D | Conventional monovision; requires greater anisometropia |
| Enhanced monofocal (+SA) | Positive SA | Slightly extended depth of focus | -0.25 to +0.25 D | -0.50 to -1.00 D or -0.25 to +0.25 D | Better tolerance of mild myopia |
| EDOF (negative-SA platform) | Negative SA (focal elongation) | Continuous range (distance to intermediate) | Plano to +0.25 D | -0.50 to -0.75 D or plano to +0.25 D | Myopia degrades image quality; a slightly hyperopic target in the dominant eye is preferable |
| Diffractive multifocal | Light splitting (multiple foci) | Distance + intermediate + near | Plano to +0.25 D | Plano to +0.25 D | Requires highly precise emmetropia; avoid residual myopia |
| Spiral optics | Optical ambiguity (spiral phase) | Potentially continuous range | Plano to +0.25 D | Plano to -0.25 D | Experimental concept; under investigation |

D – diopter; EDOF – extended depth-of-focus; IOL – intraocular lens; SA – spherical aberration.

competing focal points and may therefore reduce photic phenomena such as halos and glare. It also appears less dependent on pupil diameter and lighting conditions, an important consideration for patients' everyday visual function [8–10]. Clinically, this technology may offer a promising alternative to EDOF and multifocal IOLs by balancing a broad range of focus with visual quality, although its efficacy and predictability require further clinical evaluation.

In a landmark study, Abela-Formanek et al. [2] were the first to evaluate the efficacy and visual performance of an IOL incorporating spiral optics (RayOne Galaxy, Rayner). The investigation combined a preclinical phase with an analysis of postoperative clinical outcomes. In the preclinical phase, an advanced pseudophakic vision simulator (Real Artificial Lens Vision [RALV]) was used to assess visual quality in healthy participants without implanting an IOL. Distance, intermediate, and near visual acuity; contrast sensitivity; the defocus curve; and the size and severity of photic phenomena (halos and glare) were evaluated. Outcomes were compared directly with those obtained using a conventional diffractive trifocal IOL. Spiral optics provided a comparable range of clear vision, but with significantly less halo and glare and a clear subjective preference for the spiral lens at all viewing distances.

The clinical phase included patients who underwent bilateral implantation of the spiral IOL at multiple centers, with the primary assessment performed after 3 months of follow-up. Excellent visual acuity was achieved across the full range of distances: mean monocular distance-corrected visual acuity was approximately -0.03 logMAR for distance, 0.05 logMAR for intermediate, and 0.08 logMAR for near, with further improvement under binocular conditions. Of particular note, the defocus curve formed a flat, continuous plateau, with visual acuity maintained at 0.2 logMAR (20/32) or better over a broad range of approximately 4.0 D, extending to a viewing distance of about 35 cm.

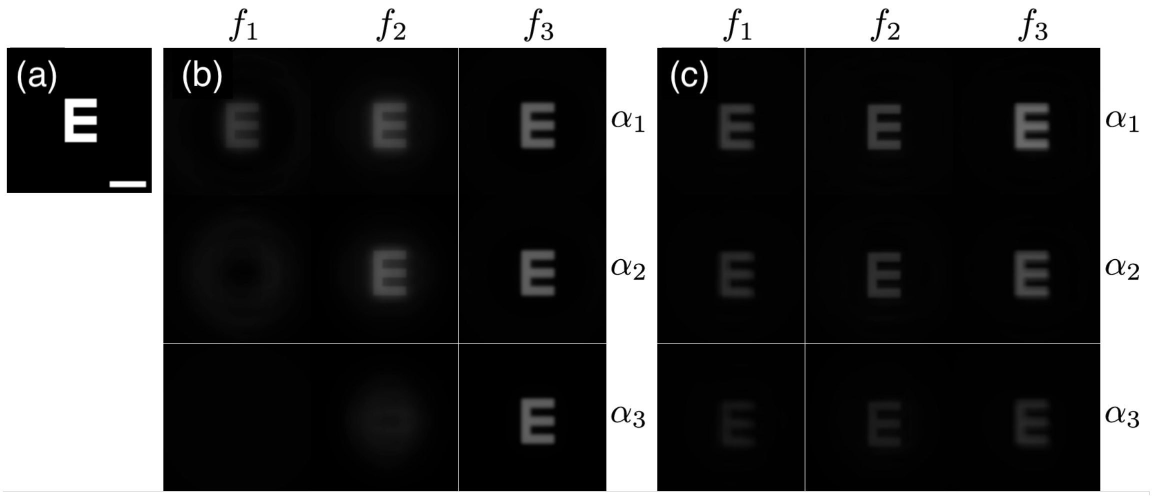
Unlike conventional trifocal IOLs, which generate discrete focal peaks, spiral optics provides a smooth distribution of optical power and reduces gaps in the defocus range, resulting in more natural transitions between viewing distances. The dysphotopsia profile was also highly favorable: more than 95% of patients reported no or only mild halos and glare, and these phenomena were significantly less severe than with diffractive lenses evaluated under comparable conditions. Spiral optics also showed superior contrast sensitivity, attributed to the absence of diffractive light splitting and reduced loss of optical energy. In the preclinical study, most participants preferred the spiral lens to the trifocal lens (up to 90%, depending on viewing distance), underscoring the importance of visual quality rather than range of focus alone.

## CONCLUSIONS

Modern cataract surgery is evolving from a procedure primarily intended to remove the opaque crystalline lens and restore optical clarity into an advanced refractive intervention aimed at providing high-quality vision across a broad range of distances. Although multifocal IOLs, particularly trifocal designs, provide excellent functional outcomes, their light-distributing architecture is associated with inherent optical trade-offs, including reduced contrast sensitivity and dysphotopsia. EDOF lenses are designed to mitigate these effects by elongating the focal range and providing a more continuous range of vision, although often at the expense of near visual performance.

FIGURE 1

Simulated images of the object shown in panel (a), obtained with (b) a trifocal lens and (c) a spiral lens and calculated for different optimal focal zones ($f_i$) and apertures ($\alpha_j$). The calibration bar in panel (a) is 5 arc min [8].



Against this background, spiral optics has emerged as a promising concept. Through continuous phase modulation, this technology may provide an extended range of focus without relying on discrete focal points or conventional multifocal light splitting. Preliminary experimental and clinical evidence suggests that spiral-optics IOLs may combine some of the advantages of multifocal and EDOF designs while improving image quality and reducing unwanted optical phenomena. Nevertheless, further well-designed clinical studies are required to confirm their efficacy and safety, as well as the long-term stability and predictability of visual outcomes.

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Dariusz Dobrowolski: substantive supervision, scientific revision.
Edward Wylęgała: study design, scientific supervision, final approval of the manuscript.

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