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ORIGINAL ARTICLE

Comparison of optical performances of intraocular lenses with different depth of field

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Abstract
Purpose: This study presents a detailed optical characterization of three intraocular lenses (IOLs) comparing two so called “enhanced range of field”, Evolux IOL and Tecnis Eyhance IOL and one so called “narrow range of field”, a standard monofocal IOL Acrysof IQ.
Methods: The measurements are performed using the PMTF optical bench, basing on the Modulation Transfer Function (MTF) to evaluate the optical performance of each lens. The MTFa, representing the area under the MTF curve, is utilized as a key and synthetic metric to quantify performance across different spatial frequencies, providing insights into the IOLs’ behavior as defocus varies.
Results: The results highlight the strengths and the weaknesses of the IOLs, with the Evolux showing a broadest depth of focus. The USAF resolution target is used to qualitatively assess the image reproduction at far, intermediate, and near distances, offering a visual representation of the IOLs’ capabilities.
Conclusions: These findings provide valuable information for selecting IOLs based on patient-specific visual requirements in cataract and refractive surgery.

Introduction

The optical characterization of intraocular lenses (IOLs) has been of critical importance in ensuring successful outcomes for patients undergoing cataract or refractive surgery. Before implantation, it’s essential to thoroughly assess the optical properties of IOLs, as well as the peculiar needs and requests of the subjects. Among the different types of such a kind of lenses, the enhanced range of field IOLs represent an advanced technology in cataract and refractive surgery. Monofocal intraocular lenses are the most frequently implanted type worldwide. The prevalence of monofocal IOLs can largely be attributed to their reliable and

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predictable visual outcomes, the lower occurrence of dysphotopsia, and their comparatively lower cost. Monofocal IOLs, however, fall short in meeting the growing demand for spectacle independence, due to modern lifestyle changes and the field of the premium lenses is expanding more and more.

For this reason, companies in recent years have invested in and are developing enhanced range of field IOLs, whose design aims to provide an extended range of vision, particularly focusing on improving intermediate vision, without significantly compromising distance vision. Unlike traditional multifocal IOLs,[1] that create multiple focal zones or diffraction patterns to enhance the clarity of an object on the retina for multiple focal lengths, these lenses create an elongated focal point, instead splitting light into distinct focal points for near, intermediate, and distance vision. In proof of principle, such feature allows a smoother transition between distances and reduces issues like halos and glare,[2] which are common with multifocal lenses. Recently, a new evidenced-based functional classification of simultaneous vision intraocular lenses has been realized.[3] In particular, extended range of vision lenses should provide enhanced performances in intermediate vision,[4,5] such as for tasks like computer work, even if they do not reach the same benefits in the near vision of the multifocal IOLs. However, they may require patients to use reading glasses for very close-up tasks, as their near vision performance isn't as strong as that of multifocal IOLs.[6] The enhanced range of field IOLs, like the standard monofocal IOLs, prioritize clear distance vision, but in addition they are designed to offer a slight extension of intermediate vision,[7–9] providing better visual performance across more distances compared to traditional monofocal lenses, even if the broadening of such a range is not larger as in the case of the extended range of vision.

Evolux (SIFI Spa, Catania, Italy) represents a novel enhanced range of field IOL, specifically designed to mitigate halos and glare typically associated with diffractive optics. This preloaded, hydrophobic acrylic IOL features a 6 mm optic body diameter and a total diameter of 13 mm. It has a biconvex optical design based on positive/negative spherical aberration distributed in the central 4.5 mm zone of the anterior surface with an aspheric monofocal periphery and a spherical monofocal surface on the back. The Tecnis Eyhance DIB00 (Johnson & Johnson Vision Care, Santa Ana, California, CA, US) is a single-piece, hydrophobic acrylic monofocal IOL featuring a modified aspheric anterior surface. This design generates a continuous power profile that transitions smoothly from the lens periphery to its center, providing an extended range of vision and enhancing visual performance, particularly for intermediate tasks. The AcrySof IQ lens is a standard aspheric monofocal hydrophobic acrylic lens with a UV and blue light filter with a 6 mm diameter and a total length of 13 mm.

In this work the characterization of the *Evolux Sifi 1110ACH* and the *Eyhance Tecnis Johnson & Johnson DIB00*[10,11] is reported in comparison with the optical performances of the monofocal IOL *Acrysof IQ Alcon SN60WF.*[12] The evaluation of the optical performances are carried out by the study of the modulation transfer function (MTF) as a function of the defocus,[13–15] which is linked to near and intermediate vision, and in condition of monochromatic illumination and fixed pupil size. In particular, among the metric that have been proposed in literature, we report the area under the curve of the MTF (MTFa) as the critical quantitative parameter to show the variation in the optical performance in the vision at different distances.[16–19] In addition, the optical reproduction of a standard reference target provides an immediate qualitative evaluation of the far, intermediate and near vision.

Material and methods

The MTF of the IOLs as a function of the defocus are measured with PMTF of LambdaX, equipped with a monochromatic light source with a wavelength of 543 nm, a pupil size of 3 mm and 4.5 mm and a Model Eye 215 (M-3, with a spherical aberration of $0.215 \pm 0.002\ \mu$m). To measure IOLs by the PMTF, a lens is inserted into a metal holder, using loops that ensure the correct housing of the IOL and with the back surface should be oriented upwards in the insert. Such a support is in turn inserted in a cuvette containing saline solution to simulate the human eye environment. Finally, IOLs are placed on the translation table, against the alignment pins. As a first step, the nominal power of IOLs were inserted in the PMTF software, provided by the manufacturer to make it easier for the operator to reach the focus of the target by a fine adjustments of the translation syst. Then, the measurement is started in the Single Vision mode, which allows the optical quality of the lenses to be evaluated in for the far vision. Then, in Through Focus-mode, all the MTF-curves are acquired by steps of power of 0.10 D over a total range of 6 D and with a resolution in spatial frequency of ~ 4 cycles/mm.

Moreover, by the PMTF, the quality of the lens is further evaluated using the USAF (United States Air Force resolution target) as target. Such a image is a standard evaluation tool used to test the resolution and provide a qualitative information about the contrast degradation of the image as a function of the defocus.

The acquired MTF-curves are then analyzed with a homemade software developed in Matlab language to retrieve further information and calculate the MTFa for each acquired value of absolute power P, i.e. the power given by the instrument in through-focus mode. The MTFa are calculated by integration of the MTF up the frequency of f_L:

$$MTFa(P) = \int_0^{f_L} MTF(P, f)\, df, \tag{1}$$

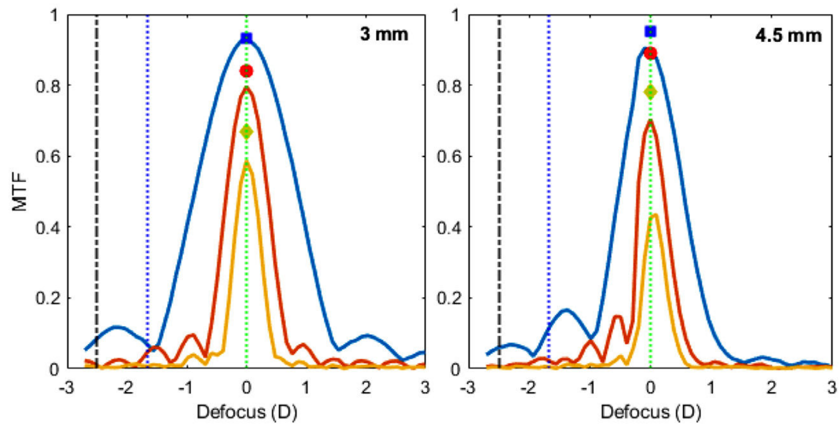
where f is the spatial frequency in cycles/mm. In this work, f_L is set 50, i.e. a value often reported as a standard in literature, and 100 cycles/mm, chosen to take into account fine details. Then, the focus F of the lens is here defined as the value of P that maximize the MTFa. To characterize the optical performance of the lens as a function of the distance of the observed object, the defocus is here defined as:

$$Defocus = F - P. \tag{2}$$

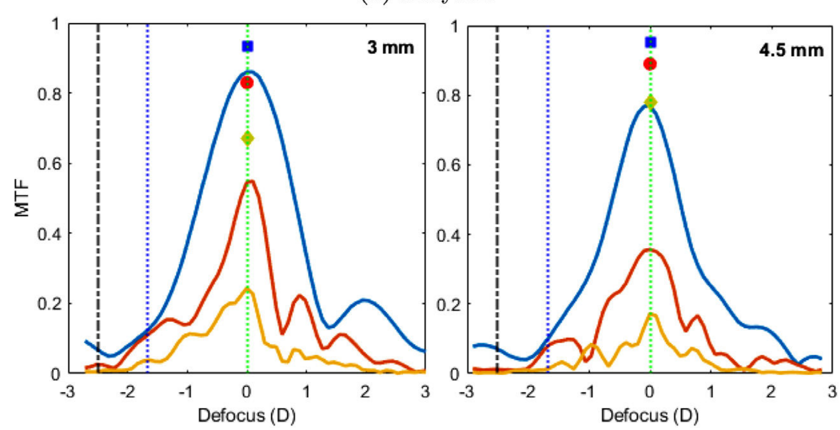
After obtaining the graph resulting from "Through Focus", the quality of the lens is further evaluated using a target defined USAF (United States Air Force resolution target). This target is a standard evaluation tool used to test the resolution and optical quality. An evaluation of the possible vision of the patient can be obtained by varying the defocus and therefore the distance of the observed object. In addition, also the point spread function (PSF) is also numerically calculated from the MTF by Fast Fourier Transform (FFT) algorithm.

Results

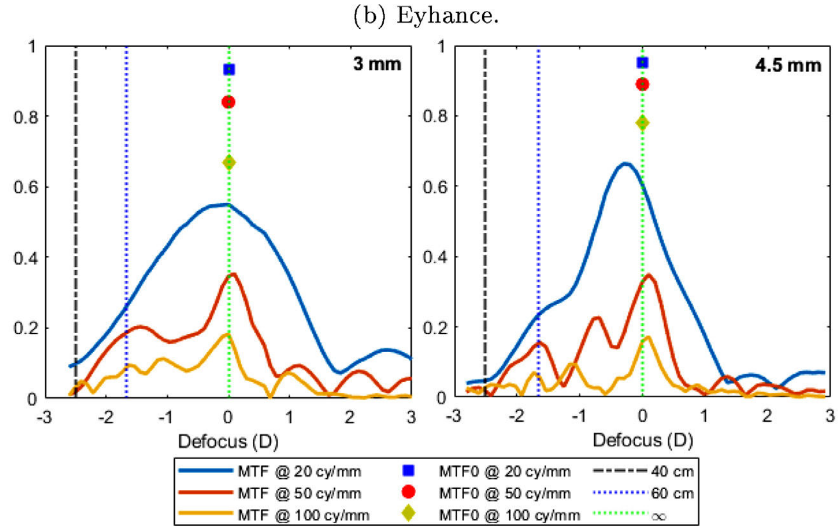
The Fig. 1a, b and c show, as a function of the defocus, the values of the MTF for a single IOL for three spacial frequencies: 20 cycles/mm (blue), 50 cycles/mm (red) and 100 cycles/mm (red). The markers shown, for the defocus=0,



(a) Acrysof.



(b) Eyhance.



(c) Evolux.

Fig. 1 MTF for three spatial frequency as a function of the defocus for the monofocal IOL Acrysof (a), the IOL Eyhance (b) and IOL Evolux (c). MTF0 is the value of the diffraction limited MTF in the focus.

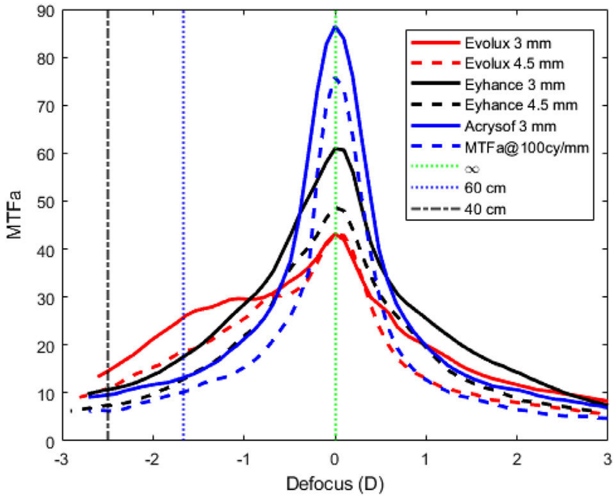


Fig. 2 MTFa (the integral of the MTF, Eq. (1)) vs defocus.

represent the values of these frequencies for the diffraction limited MTF (MTF0). In addition, the vertical dashed lines are inserted to indicate three important defocus which correspond to three distances of vision: defocus 0 D ("infinite", far distance, that indicates the focus), −1.67 D (60 cm, intermediate) and −2.5 D (40 cm, near). Hence, such lines are references to show how the values of the reported values of spatial frequencies behave in terms of MTF.

The monofocal IOL Acrysoft (Fig. 1a) shows very high values of the MTF for the far-vision, while the optical performances abruptly decay below −1.5 D of defocus and then providing a considerable degradation in intermediate and near vision. The MTF of the Eyhance (Fig. 1b) shows, in comparison to the Acrysof, reduction of MTF in the focus and an enhancement for negative values of defocus up to the one which correspond to the intermediate vision. The Evolux (Fig. 1c), compared to the Acrysof, is characterized by a notable decrease of the MTF for the far distance, together with a considerable depth of focus that could preserve the contrast also in the near vision.

The MTFa curve of the three IOLs are shown in Fig. 2, highlighting the performance of the IOLs by accounting for the contribution of all spatial frequencies up to f_L =100 cycles/mm. These trends allow for the visualization of a figure of merit, as well as a metric, that showcases the strengths and weaknesses of the lenses as defocus varies. It is evident that the Acrysoft delivers very high performance for distance vision, but at the cost of a drastic decline in quality for intermediate and near distances. The Eyhance shows intermediate values at focus and manages to limit contrast degradation, at least for intermediate distances. The Evolux, while having the poorest performance at focus among the IOLs studied in this paper, exhibits a much more gradual decline in quality for closer distances. The MTFa curve of the -IOL Evolux suggests that this lens should therefore offer the best optical performance for both near and intermediate vision.

The Table 1 shows the summary of the results achieved in this work, reporting the focus and the ratio ρ between the MTFa and the MTFa of the diffraction limit (MTFa0) for the frequencies up to f_L:

$$\rho = \frac{\text{MTFa}}{MTFa0} \tag{3}$$

In correspondence of the focus (far vision), such a ratio also represent the Strehl-Ratio of the IOL. The value of the focus is calculated with the maximization of the MTFa upon the values of power probed in the "Through Focus" mode during the acquisition by the PMTF.

The Fig. 3 shows the USAF target for the pupil size of 3 mm of the IOLs, offering a qualitative proof of the results shown above. The left column pertains to the far vision, the center to the intermediate and the right one reports the case of near vision. The corresponding USAF for the pupil size of 4.5 mm (not shown here) are very similar to those presented in Fig. 3, only they are slightly more degraded. As largely expected, the Acrysof clearly shows the best preservation of the contrast of the original image in the far vision, while the details undergo severe degradation as the defocus becomes different from 0. The Eyhance and the Evolux do not show substantial differences in image sharpness at their corresponding foci. Both the IOLs exhibit better details in out-of-focus images, with the Evolux clearly performing best in near vision.

Finally, the Fig. 4 shows, for the same cases of the Fig. 3, the PSF. The broadening of the PSF is linked to a decrent of the optical performances of the IOLs, in particular when the defocus increases.

Table 1 Summary of the results for the ratio ρ between the MTFa (the integral of the MTF, Eq. (1)) and the MTFa of the diffraction limit (MTFa0) for different pupil diameters. The values of the frequencies f_L are measured in cycles/mm.

IOL			ρ@∞		ρ@60cm		ρ@40cm
Pupil	Name	f_L=50	f_L=100	f_L=50	f_L=100	f_L=50	f_L=100
3 mm	Acrysof	98 %	94 %	24 %	14 %	17 %	10 %
	Eyhance	83 %	67 %	29 %	20 %	19 %	12 %
	Evolux	59 %	47 %	39 %	29 %	24 %	16 %
4.5 mm	Acrysof	89 %	77 %	18 %	10 %	11 %	6.4 %
	Eyhance	68 %	50 %	22 %	13 %	13 %	7.5 %
	Evolux	57 %	43 %	29 %	19 %	18 %	11 %

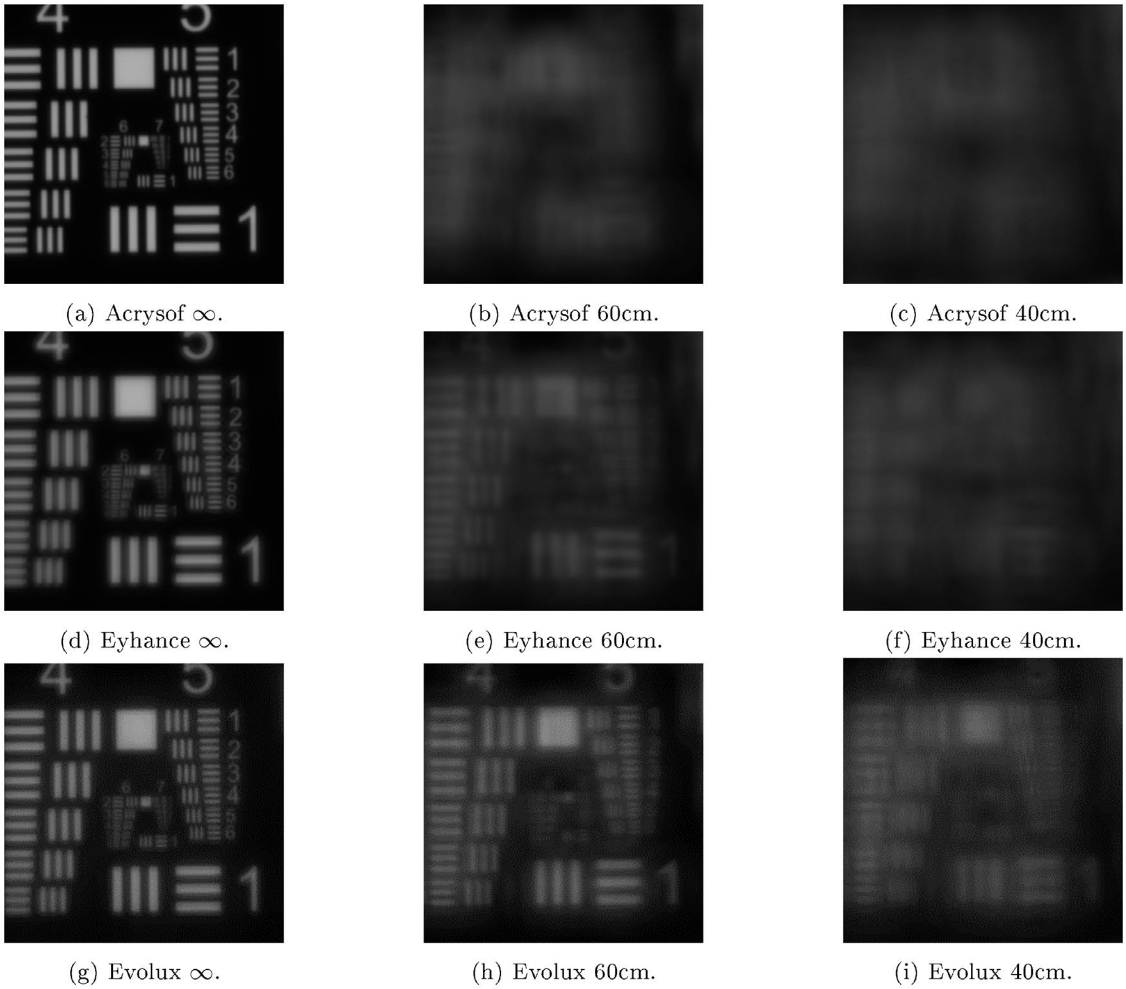


Fig. 3 Comparison of the targets USAF of different IOLs, for three distances of vision and for the pupil size of 3 mm.

Conclusions

This study focused on the optical characterization of three intraocular lenses (IOLs): Evolux and Tecnis Eyhance IOLs, that represent the enhance range of field, and the Acrysof IQ as a standard monofocal IOL for optical comparison. The results demonstrated that while the latter IOL provides excellent performance for far distance vision, while its capabilities diminish significantly at intermediate and near distances, making it less suitable for patients who require functional vision across a broader range. The optical measurements have involved both the pupil size of 3 mm and 4.5 mm and with a monochromatic illumination. The Tecnis Eyhance DIB00, designed to enhance intermediate vision while maintaining good distance vision, showed a balanced performance. It outperformed the monofocal IOL in intermediate tasks, offering a moderate extension of the depth of focus. This should make an option for patients who desire some degree of versatility in their vision, but are still primarily focused on distance clarity, because the losses in near vision are significant. This is confirmed by the literature, where some studies report subjective good vision for long distance, together with an improvement in the intermediate compared to standard monofocal lenses outcomes.[20,21]

On the other hand, the Evolux lens displayed the greatest depth of focus among the studied IOLs, particularly at closer distances. Although it showed a reduction in MTF values at far distances compared to the monofocal IOL, but comparable to the Eyhance, its gradual decline in optical performance across various defocus levels suggests that it offers better near and intermediate vision. A recent study confirms that Evolux showed a significantly superior visual performance at intermediate distance compared to the Eyhance IOL.[22]

The particular Evolux refractive philosophy, without steps or rings can be considered a compelling choice for patients who prioritize a smoother visual transition between different distances, especially for tasks requiring clear vision at closer ranges. Moreover, such an IOL shows the minor decrements in the MTF in the focus as the pupil size changes. In summary, Evolux and Eyhance IOLs offer distinct advantages

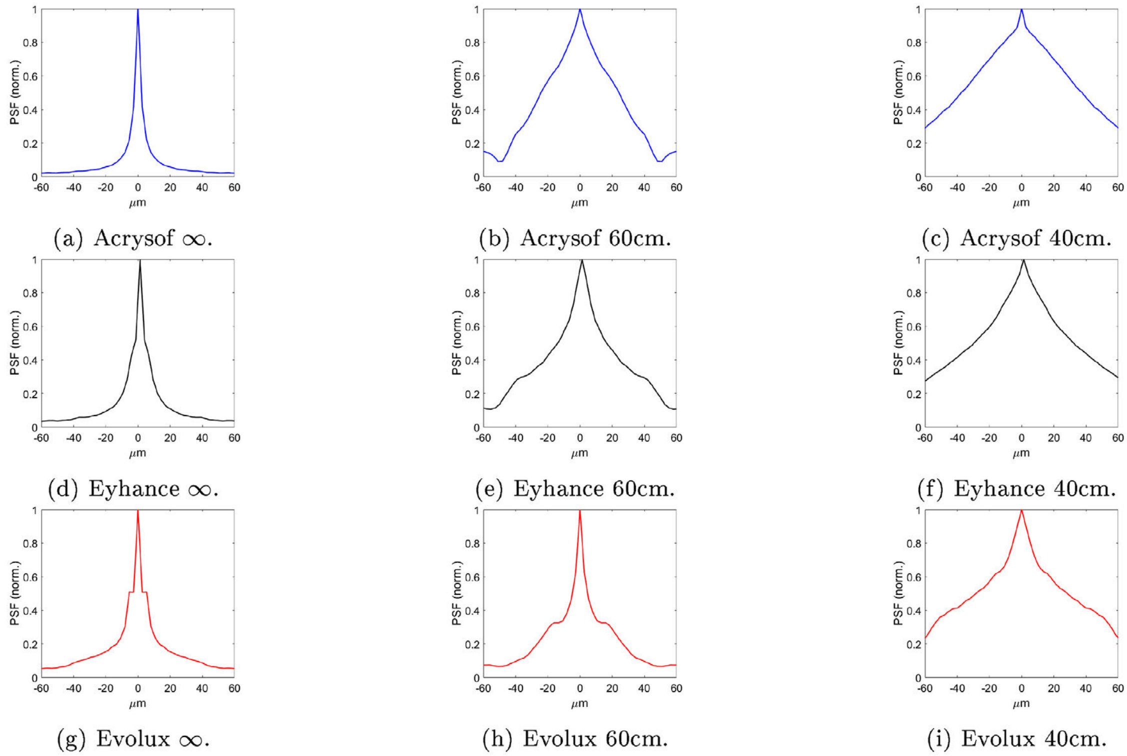


Fig. 4 PSF calculated for three distances of vision and for the pupil size of 3 mm.

over traditional monofocal lenses, depending on the visual needs of the patient. The Evolux stands out for its broad depth of focus, while the Eyhance provides a moderate improvement in intermediate vision compared to a standard monofocal, without sacrificing too much distance clarity. Therefore, the choice between these advanced IOLs should be made based on the specific lifestyle and visual demands of each patient.

Availability of data and materials

The data will be available in case of reasonable request by corresponding author.

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Authors' contributions

Design of study (FT,AG,GR,RM,MG,ST); Data collection (AG and CM); Analysis and interpretation of data (FT,AG,CM,ST, LF,GR,RM,MG and ST); Writing of article (FT, AG, GR, RM and ST); Critical revision and final approval of article (All authors).

Declaration of competing interest

The authors declare that they have no conflicts of interest.

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