TITLE: STEREO-ACUITY IN PATIENTS IMPLANTED WITH MULTIFOCAL INTRAOCULAR LENSES: IS THE CHOICE OF STEREOTEST RELEVANT?

Running Head: Stereo-acuity with multifocal intraocular lenses

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ABSTRACT

Purpose: A randomized and double-blind study design was implemented to assess the stereo-acuity in patients symmetrically implanted with four types of multifocal intraocular lenses (MIOLs), compared to a monofocal lens (control group). In addition, the influence of the type of test employed for the evaluation of stereo-acuity was explored.

Materials and Methods: Six months after cataract intervention, stereo-acuity was measured with the Titmus and TNO stereotests in 143 patients implanted with one of the following MIOL lens types: hybrid spherical SN60D3, hybrid aspheric SN6AD1, diffractive aspheric ZMA00 and refractive spherical NXG1. A control group implanted with the monofocal aspheric ZA9003 (in which stereoacuity was measured with a near addition) was also included in the study.

Results: Statistically significant better stereo-acuity was found in the monofocal group with both stereotests (except for the SN60D3 group with the Titmus test) (all $p < 0.001$). No significant differences in stereo-acuity between MIOLs were found using the Titmus test. However, with the TNO, patients implanted with hybrid diffractive MIOLs exhibited statistically significant worse stereo-acuity than those with the refractive design (SN60D3, $p < 0.001$; SN6AD1, $p = 0.006$).

Conclusions: Patients implanted with MIOLs have worse stereo-acuity than those implanted with monofocal IOLs due to the decrease in retinal image contrast originating in the simultaneous presence of two images. A wavelength-based stereotest such as the TNO induces large differences in image contrast between fellow eyes implanted with diffractive-based MIOLs, which may result in an underestimation of the real stereoacuity of the patient.

KEY WORDS

Cataract Surgery; Chromatic Aberration; Diffractive Optics; Multifocal Intraocular Lens; Stereo-acuity

Currently available multifocal intraocular lenses (MIOLs) allow the pseudophakic eyes to correctly focus at far and near distances and to obtain functional vision at intermediate distances. Conversely, monofocal intraocular lenses (IOLs) are designed to correct the eye refraction at one specific object distance, usually far vision, thus requiring spectacle correction to focus objects placed at closer distances. MIOLs present a variety of designs: from purely refractive to full aperture diffractive, and hybrid diffractive-refractive. Whereas refractive MIOLs provide two or more foci by varying the surface curvature in the sectors defined within the lens aperture, diffractive MIOLs rely on diffractive principles to split the incoming light energy into two or more foci. Hybrid designs[1] combine refractive and diffractive zones on the same surface, commonly a central diffractive zone and a refractive periphery.

All MIOL designs lead to simultaneous vision, which has been documented to result in a variety of photic phenomena described as halos and/or glare[2], with their negative impact on vision being modulated by a number of factors, such as pupil size and illumination conditions, lens power and addition[3], lens design, and sensitivity and possible neuro-adaptation of the patient to the phenomena, among others. Besides, the simultaneous imaging of near and distant objects, in addition to the possible presence of post-operative residual defocus or astigmatism, as well as higher order aberrations (such as spherical aberration (SA) and coma), have been found to lead to a reduction in contrast sensitivity[4] and may also influence the natural capability of human binocular vision for three-dimensional perception.

Stereoscopic vision, depth perception or stereopsis depends on tiny disparities between the retinal images of the two eyes[5] and may be affected by the degraded optical quality in one or both eyes and by binocular impairment[6-10]. Previous studies have assessed differences in stereo-acuity between patients with bilateral and unilateral implantation of both monofocal and multifocal lenses[11-13]. Besides, differences between stereo-tests have been reported in patients with bilateral implantation of monofocal or multifocal IOLs. Thus, for instance, whereas Ferrer-Blasco and co-workers[14] failed to find any statistically significant differences in the mean stereo-acuity of patients with bilateral implantation of an aspheric bifocal AcrySof ReSTOR (SN6AD3) IOL, as measured with the Titmus and Random dot stereotests (both tests are based on the vectographic technique, and require patients to employ polarizing filters), the same authors reported significant differences with the Howard-Dolman device, which was considered as the most sensitive and accurate procedure to determine stereo-acuity[15]. The Howard-Dolman apparatus, however, is rarely used in clinical practice, with clinicians opting for either vectographic tests, such as the Titmus Wirt test, Randot tests, or anaglyphic tests such as the TNO, which is a highly dissociative stereotest that does not present monocular cues. In general, however, clinical studies rely on just one of the methods mentioned above and do not provide specific reasons to justify the choice of that type of stereotest.

It was the aim of the present study to assess the differences in stereo-acuity of patients symmetrically implanted with four different, commonly used, MIOL designs (refractive spherical, diffractive aspheric and hybrid refractive-diffractive aspheric and spherical), as well as an aspheric monofocal IOL (control group). Six months after cataract intervention, patients were evaluated with two different stereotests regularly employed in clinical practice (Titmus and TNO) to determine the influence of the optical characteristics of each test on the stereo-acuity scores for each lens type. To the best of our knowledge, this has not been properly addressed in the literature. It was hypothesized that, unlike the Titmus test, the principle of chromatic disparity used by the TNO test (red/green glasses) may induce significant wavelength-dependent differences in diffractive-based MIOLs in at least two basic aspects: add power of the lens and energy efficiency at the near focus.

MATERIAL AND METHODS

Patients

This prospective, randomized, double-masked clinical trial was conducted at the Ophthalmology Department of *Santa Creu and Sant Pau* Hospital in Barcelona, Spain. Inclusion criteria were patients with cataract aged between 45 and 80 years, potential monocular postoperative visual acuity of 0.1 logMAR or better, preoperative corneal astigmatism lower than 1.5 D, symmetrically bilateral MIOL implantation, patient motivation and desire for spectacle correction independence for near and distance vision.

Patients with strabismus, ocular or systemic pathology with potential risk of ocular manifestations, previous ocular surgery, as well as those reporting critical visual demands (such as night-time drivers), unrealistic expectations or difficulties with the examinations or follow-ups were excluded from the study. Postoperatively, patients with surgical complications (such as pupil trauma, vitreous loss, extra capsular implant, IOL tilt or descentration) and patients with monocular distance corrected near visual acuity (DCNVA) worse than 0.2 logMAR or those with more than 0.1 logMAR difference in DCNVA between both eyes were also excluded from the study.

Multifocal intraocular lens implantation was randomly determined using a 1:1:1:1 block randomization scheme generated by SPSS 17 for Windows. For comparison purposes, an additional group of patients symmetrically implanted with a monofocal IOL was also included in the study. The same inclusion/exclusion criteria were implemented for the control group.

This study was designed according to the tenets of the Declaration of Helsinki as revised in Tokyo in 2004, and received the approval of an institutional review board (*Santa Creu and Sant Pau* Hospital in Barcelona, Spain). All patients were presented and signed an informed consent in which they agreed to participate in the study.

Stereo-acuity tests

The Titmus test (**Fig. 1 top**) uses polarized glasses to induce the retinal disparity (dissociation) that is necessary for the perception of depth. The anaglyphic TNO test (**Fig. 1 bottom**) consists of random dot chromatic stimuli, which require glasses with red-green filters to give rise and convey disparity. Disparity varies between 40 and 800 arc seconds for the Titmus test and between 15 and 480 arc seconds for the TNO. In addition, the TNO test includes a set of non-quantitative figures with a disparity higher than 480 arc seconds.

It may be noted that with the TNO test the disjoint spectral transmittances of the red-green chromatic filters (**Fig. 2**) allow patterns of different spectral content to be presented to each separate eye. Interestingly, the larger spectral transmittance of the red filter (**Fig. 2(a)**) compensates for the lower spectral sensitivity of the eye in the red. **Fig. 2(b)** shows the multiplication of curves of transmittance given in **Fig. 2(a)** by the CIE luminous efficiency curve of the eye in photopic conditions, thus validating that the TNO test is intended to produce similar luminous flux efficiency in both eyes, i.e., the performance of this test assumes the comparison of images of similar luminance, provided the spectral distribution of the white light source and the test picture reflectance are adequate. This is indeed a relevant aspect when exploring the performance of any diffractive optical element, which is strongly dependent on the wavelength of the incoming light[16].

Intraocular lenses

Four types of MIOLs and one type of monofocal IOL were used for this study (**Table 1**). The hybrid refractive-diffractive AcrySof ReSTOR (Alcon) lens has an apodized diffractive design in the central part (3.6 mm) of the anterior surface, and a refractive periphery. The apodization consists of a gradual reduction of the height of the diffractive steps from center to periphery. This design aims at directing a higher amount of the incoming energy to the distance focus with large diameter pupils, whereas for small pupils the energy distribution is approximately the same at each foci[1]. Two types of hybrid apodized-diffractive MIOLs were included in this study: the spherical SN60D3, with addition of +4.0 D (+3.2 D at the spectacle plane) and the aspheric SN6AD1, which compensates for a corneal SA of 0.10 µm (for a 6 mm pupil diameter) and has an addition of +3.0 D (+2.4 D in the spectacle plane).

The refractive spherical ReZoom NXG1 (AMO) has an anterior surface including five concentric zones (rings) which alternate for distance (zones 1, 3 and 5) and near vision (2 and 4). As a consequence, light distribution between the two foci is pupil dependent. The addition for near vision is +3.5 D (+2.6 D at the spectacle plane).

The diffractive Tecnis ZMA00 (AMO) has an anterior aspheric surface to compensate for a corneal SA of 0.27 µm (for a 6 mm pupil diameter) and a posterior spherical surface with a diffractive design. The addition in this lens is +4.0 D (+3.0 D at the spectacle plane). Because of the purely diffractive profile design of this lens, light energy is evenly distributed between the distance and near foci regardless of pupil diameter.

Finally, the Tecnis ZA9003 is a monofocal IOL with the same aspheric design as the ZMA00 MIOL.

Surgical technique

A single experienced surgeon (M.A.G) conducted all surgeries. A 2.75 mm clear corneal incision was performed in the steepest corneal meridian and, for corneal astigmatism over 1.00 D, a secondary paired incision was executed at 180^{o} to reduce residual astigmatism. After the phacoemulsification of the crystalline lens, the IOL was inserted in the capsular bag using the injectors recommended by each manufacturer. The goal of all interventions was emmetropia.

Stereopsis measurements

Six months after the surgery all patients underwent a complete ophthalmological examination including monocular corrected distance (CDVA) (Early Treatment Diabetic Retinopathy Study (ETDRS) charts) and near visual acuity (DCNVA) (Tumbling E), as well as photopic pupil diameter evaluation (infrared Colvard pupillometer), whereupon a single optometrist (C.V.) performed all stereopsis measurements under photopic conditions (85 cd/m^2) at a distance of 40 cm. Patients implanted with MIOLs used their best distance correction while patients implanted with monofocal IOLs were provided with an addition of +2.5 D to correctly focus the stereo-acuity test.

Both Titmus and TNO tests were passed successively and in random order to all patients. In addition, aiming to further assess the influence of the anaglyphic glasses (red/green) of the TNO test in eyes implanted with MIOLs, measurements were repeated with a +2.5 D lens in place, with which patients observed the test with the distance focus of the MIOL. Patients were allowed minute modifications in their viewing distance accounting for differences in MIOL add power and aiming at ensuring the double-masked design of the study.

Data analysis

Statistical analysis was performed with the SPSS software 17.0 for Windows. Sample size was determined by considering a Cohen *d* effect size of 0.8 and an alpha level of 0.05, resulting in a recommended sample size of approximately 26. Besides, as there were small deviations in the number of patients implanted with each lens type, a subsequent backward evaluation of unequal groups was performed to determine the equivalent minimum sample size for pair-wise comparisons between groups. It must be noted, however, that differences in sample size are only relevant if there is a compromise in the homogeneity of variance assumption, which was not considered to be the case with the present data.

All data were analyzed for normality using the Kolmogorov-Smirnov test, revealing several instances of non-normal distributions, which recommended non-parametric statistical analyses. The Kruskal-Wallis test was employed to examine differences in stereo-acuity values between the lenses (the four MIOLs and the monofocal IOL) and statistically significant differences were then explored pair-wise with the Mann-Whitney test. In addition, the Mann-Whitney test was also employed to examine differences in TNO test scores within each type of MIOL, with and without the +2.50 D lens over the distance correction. A p value of <0.05 was considered to denote statistical significance throughout the study.

RESULTS

A total of 143 patients (54.2% female) were included in the study: 25 were implanted with the SN60D3, 23 with the SN6AD1, 28 with the ZMA00, 24 with the NXG1 and 34 with the ZA9003. The age of the patients was 68.68 ± 7.79 years (Mean ± SD). Postoperative CDVA, DCNVA and photopic pupil diameter values for all lens groups are summarized in **Table 2**. No statistically significant between-group differences were found regarding age, gender distribution, CDVA and photopic pupil diameter.

Stereo-acuity with different lens types and stereotests

Table 3 summarizes the measured stereo-acuities. Within the same type of lens, stereo-acuity scores were significantly better with the Titmus than with the TNO in all cases (all $p < 0.001$). Indeed, with the Titmus test, a higher percentage of patients implanted with MIOLs reached the best possible stereo-acuity value that can be measured with this test (40 arc sec).

Upon examining each test separately, a between-group statistically significant difference was encountered for both TNO and Titmus measurements ($\chi^2 = 18.028$; $p<0.001$ and $\chi^2=11.346$; $p=0.023$, respectively). A *post-hoc* pair-wise comparison revealed that, with the TNO test, patients implanted with the monofocal lens obtained better stereo-acuity than those implanted with any of the MIOLs (SN60D3 $Z = -6.802$; $p < 0.001$, SN6AD1 $Z = -6.194$; $p < 0.001$, NXG1 $Z = -5.390$; $p < 0.001$ and ZMA00 $Z = -5.703$; $p < 0.001$). Similarly, for the Titmus test, monofocal lenses were also found to offer a superior performance when compared with all MIOLs, with the exception of the spherical hybrid SN60D3 (SN6AD1: $Z = -3.185$; $p = 0.001$; NXG1: $Z = -2.442$; $p = 0.015$; and ZMA00: $Z = -2.353$; $p = 0.019$).

The group of patients implanted with diffractive-based MIOLs (SN60D3, SN6AD1 and ZMA00) presented the worst stereo-acuity with the TNO test and the largest between-test differences when compared with the values of the Titmus test. Indeed, a small number of patients failed to present any measurable stereo-acuity with the TNO test (12% with the SN60D3; 13% with the SN6AD1; 4% with the NXG1 and 7% with the ZMA00). Besides, statistically significant differences were encountered with the TNO test between the refractive NXG1 and the hybrids SN60D3 ($Z = -3.748$; $p < 0.001$) and SN6AD1 ($Z = -2.722$; $p = 0.006$), as well as between the diffractive ZMA00 and the hybrid SN60D3 ($Z = -3.006$; $p = 0.003$). With the Titmus test, no statistically significant differences were found between the different MIOLs.

Stereo-acuity with the TNO test with and without the +2.50 D lens

Measurements with the TNO test were repeated with the a +2.5 D lens over the best distance refraction in all MIOLs, thus compelling patients to use the distance focus of the MIOL instead of the near focus for the visualization of the test. Stereo-acuities measured in these conditions are presented in **Table 4**.

Stereo-acuity values were found to be better with than without the +2.5 D lens, although the monofocal lens group still exhibited the best stereo-acuity scores, with a majority of monofocal patients reaching 60 arc seconds. The Mann-Whitney test was used to investigate the statistical significance of the differences in stereo-acuity within each type of MIOL, with and without the +2.5 D lens, revealing that, whereas better stereo-acuity scores were obtained with the +2.5 D lens in patients implanted with the diffractive-based MIOLs (SN60D3: $Z= -4.388$; $p < 0.001$; SN6AD1: $Z = -3.747$; $p < 0.001$; ZMA00: $Z = -3.314$; $p = 0.001$), patients implanted with the refractive-based MIOL had similar stereo-acuity results with and without the +2.5 D lens.

DISCUSSION

The aim of the present study was to evaluate and compare the stereo-acuity of patients implanted with 4 different types of MIOLs, as well as a monofocal lens, and to explore the possible influence of the test employed for this measurement. As such, it was revealed that both with the Titmus and TNO tests, patients implanted with the monofocal lens, when measured with a near addition, presented statistically significant better stereo-acuity scores than those implanted with any of the MIOL types, with the exception of the SN60D3 MIOL with the Titmus test. Other authors have also uncovered similar stereo-acuity outcomes when comparing the SN60D3 and several designs of monofocal lenses[17-19].

With the TNO test, a statistically significant better stereo-acuity was disclosed with the refractive MIOL than with the diffractive-based MIOLs designs, in agreement with previous works[20]. In addition, whereas an improvement in stereo-acuity was revealed when patients implanted with diffractive-based MIOLs observed the test with the distance focus instead of the near focus, this improvement was not evidenced in the refractive lens group.

It has been reported[21] that stereoacuity depends on image contrast and, as a consequence, the loss of stereopsis with age is related to the loss of contrast sensitivity[22]. Other authors, however, noted that, even if the bilateral implantation of MIOLs often resulted in a reduction in contrast sensitivity, the overlapping of the focused image at near by the blurred image at distance did not lead to significant changes in stereo-acuity[14].

The present findings, however, evidence differences in stereo-acuity between the monofocal and multifocal lens groups, particularly with the TNO test. It has been previously documented that following refractive surgery, stereopsis degrades as a consequence of residual refractive errors, unequal blur between the two eyes and decreased retinal image contrast[6-8,10]. Hayashi and co-workers[23], for example, mentioned large differences in spherical equivalent refractive error between fellow eyes as the main factor affecting stereopsis in patients implanted with monofocal IOLs, followed by old age and large pupil diameter. In the present study, given that patients with inter-ocular differences in DCNVA larger than 0.1 logMAR were not included, unequal blur had to be discarded as a possible explanation for the reduction in stereo-acuity. However, the actual effect on stereo-acuity of the small, although statistically significant differences in DCNVA between lens groups may need to be taken into consideration and shall be explored in detail in future studies. Further investigation is also needed to determine the lack of statistically significant differences between the monofocal group and the group with the SN60D3 MIOL with the Titmus test.

Another important issue to consider is the large difference in stereo-acuity values between both tests employed for its evaluation, with the Titmus test resulting in better scores than the TNO test for all MIOLs types. To explain these findings, it is necessary to explore the mechanisms involved in distance and near image focusing of refractive and diffractive-based MIOLs. In particular, with diffractive-based MIOLs both add power and diffraction efficiency at the near focus are wavelength-dependent[16], a factor that needs to be taken into account when using a chromatic-based test like the anaglyphic TNO stereotest. It is worth emphasizing that, to the best of our knowledge, this point has not yet been addressed in previous publications describing stereo-acuity measurements with the TNO test in patients implanted with diffractive MIOLs.

For any type of IOL, variations in the refractive index of the lens material with wavelength (referred to as the material chromatic dispersion) result in different wavelengths being focused at different axial positions, thus inducing chromatic differences in the dioptric power of the lens. The strength of this effect depends on the Abbe number of the lens material: the lower the Abbe number, the larger the chromatic differences in the dioptric power of the lens. Thus, for an IOL with refractive index $n(\lambda_1)$

and dioptric power $P(\lambda_1)$ in an aqueous medium, if the wavelength is changed to λ_2 there is a dioptric power variation $\Delta P_{dioptric} = P(\lambda_2) - P(\lambda_1)$, which is given by:

$$\frac{\Delta P_{dioptric}}{P(\lambda_1)} = \frac{n(\lambda_2) - n(\lambda_1)}{n(\lambda_1) - n_{aqueous}} \qquad \textbf{Eq. 1}$$

where $n(\lambda_2)$ is the refractive index of the lens at wavelength λ_2. In the case of a MIOL, **Eq. 1** applies to both the near and distance focus and it may be used to determine the dioptric power difference for a given focus (either the distance or the near one) between two identical MIOLs when each of them is illuminated with a different wavelength.

This phenomenon is of relevance in any stereopsis measurement with the anaglyphic TNO test in patients implanted with MIOLs. Indeed, in an scenario of maximum chromatic dispersion, corresponding to a material with the lowest Abbe number, such as the acrylic material of the hybrid MIOLs used in the present study[24], given wavelengths of λ_1=550 nm and λ_2=625 nm (the wavelengths of maximum transmittance of the filters of the TNO glasses) and associated refractive indices of $n(\lambda_1)$=1.5500 and $n(\lambda_2)$=1.5426[21], and using a dioptric power $P(\lambda_1)$ of 21.2 D (the mean value of the lenses in the present study), a $\Delta P_{dioptric}$= -0.73 D is calculated **(Eq. 1)**. It may be noted, however, that by using the chromatic dispersion data of the crystalline lens[25], a similar $\Delta P_{dioptric}$ of -0.85 D is determined for healthy eyes, which do not experience any problem to achieve good stereopsis scores with the TNO test. Therefore, it may be concluded that the chromatic test-induced dioptric power variations between eyes implanted with MIOLs have a negligible impact in the scores of stereopsis.

These considerations, however, are only partially valid for diffractive-based MIOLs. In effect, whereas chromatic dispersion of the material is the only relevant factor with refractive MIOLs, diffractive-based MIOLs use the base dioptric power of the lens and the zero (*m=0*) and first (*m=1*) diffraction orders for the distance and near foci, respectively, that is, there is a combination of two effects: chromatic dispersion and dependence of the diffraction orders on wavelength.

The distance focus of the MIOL (*m=0*) is only affected by chromatic dispersion[16] which, as shown above, has a negligible effect. The add power (P_{add}) needed for the near focus (*m=1*), however, exhibits a linear dependence with the wavelength, as governed by the equation:

$$P_{add}(\lambda) = \lambda \frac{1}{r_0^2} \qquad \textbf{Eq. 2}$$

where r_0 is the radius of the first diffractive zone. In turn, variations in add power (ΔP_{add}) resulting from wavelength changes (from λ_1 to λ_2) are determined by[26]:

$$\frac{\Delta P_{add}}{P_{add}(\lambda_1)} = \left(\frac{\lambda_2}{\lambda_1} - 1 \right) \qquad \textbf{Eq. 3}$$

Given an add power of +4.0 D for a wavelength of λ=550 nm, and the corresponding change in wavelength arising from the TNO filters (λ_1=550 nm to λ_2=625 nm), a ΔP_{add} of + 0.54 D is obtained. Total changes in add power may be obtained by:

$$\Delta P_{total} = \Delta P_{add} + \Delta P_{dioptric} \qquad \textbf{Eq. 4}$$

Resulting in ΔP_{total} = *0.54*-0.73 = -0.19 D in our example, that is, for diffractive-based MIOLs TNO-induced chromatic differences are smaller in the near than the distance focus.

In order to explain the poor stereopsis scores with the TNO test in the group of patients implanted with diffractive-based MIOLs, and their subsequent improvement with the +2.5 D lens (i.e., when using the distance focus to view the test), it may be noted that wavelength also has a significant influence on diffraction efficiency[16,26], that is, on the relative energy distribution to the near and distant foci. When wavelength is increased from λ_1=550 nm to λ_2=625 nm, diffraction efficiency for the near foci decreases from

0.41 to 0.29, leading to a loss of contrast of the focused near image, which is overlaid by a blurred, albeit more “energetic” distance image. Patients observing the TNO test with the near focus see a high contrast image with one eye (green filter) and a lower contrast image with the fellow eye (red filter), leading to difficulties in merging the two images, as required for a good stereoscopic vision. This effect would be absent when using the distance focus to observe the test, as well as in refractive lens designs, in which no differences were found with, or without, the +2.50 D lens.

In conclusion, the present findings disclosed a significant reduction in stereopsis in patients implanted with MIOLs, when compared with monofocal IOLs. Furthermore, stereo-acuity scores were found to be influenced by the test employed for this evaluation, particularly in diffractive-based lens designs, as a consequence of several wavelength dependent phenomena which should be taken into consideration when using anaglyphic tests such as the TNO. These findings may be of relevance to clinicians when assessing the stereo-acuity of patients implanted with different types of intraocular lenses.

DECLARATION OF INTERESTS

The authors report no conflicts of interest. The authors alone are responsible for the content and writing of the paper. The study was supported by project DPI2009-08879 from the Spanish Ministerio de Ciencia e Innovación y Fondos FEDER.

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TABLES

Table 1: Characteristics of the IOLs under evaluation (DF: distance focus; NF: near focus)

	ReZoom NXG	**AcrySof ReSTOR SN6AD1**	**AcrySof ReSTOR SN60D3**	**Tecnis ZMA00**	**Tecnis ZA9003 (monofocal)**
Optics	Refractive	Hybrid (center diffractive, periphery refractive)	Hybrid (center diffractive, periphery refractive)	Diffractive	
Geometry	Spherical & aspheric transitions	Aspheric	Spherical	Aspheric	Aspheric
ADD (spectacle plane)	+3.50 D (+2.60 D)	+3.00 D (+2.40 D)	+4.00 D (+3.20 D)	+4.00 D (+3.00 D)	0.00 D
Light energy distribution (2 mm pupil)	83% DF	40% DF 40% NF	40% DF 40% NF	41% DF 41% NF	100% DF
Light energy distribution (5mm pupil)	60% DF 30% NF	84% DF 6% NF	84% DF 6% NF	41% DF 41% NF	100% DF

Table 2: Demographic and postoperative characteristics of the sample under study (CDVA: binocular corrected distance visual acuity; DCNVA: binocular best distance corrected near visual acuity). * Denotes statistical significance.

	ReZoom NXG	**AcrySof ReSTOR SN6AD1**	**AcrySof ReSTOR SN60D3**	**Tecnis ZMA00**	**Tecnis ZA9003 (monofocal)**	**p**
n	24	23	25	28	34	
Female (%)	52.6	55.3	54.1	55.6	53.7	0.288
Age (years) Mean (SD)	68.1 (7.3)	69.3 (10.7)	67.7 (7.9)	68.2 (7.6)	70.1 (5.6)	0.754
Photopic Pupil Diameter (mm) Mean (SD)	3.17 (0.32)	3.23 (0.33)	3.41 (0.27)	3.19 (0.42)	3.28 (0.38)	0.102
Postoperative CDVA logMAR Median (range)	0.00 (0.00-0.16)	0.02 (0.00-0.20)	0.01 (0.00-0.20)	0.00 (0.00-0.18)	0.02 (0.00-0.20)	0.130
Postoperative DCNVA logMAR (40 cm) Median (range)	0.17 (0.05-0.19)	0.12 (0.00- 0.15)	0.09 (0.00-0.19)	0.12 (0.00-0.19)	0.04 (0.00-0.18)	< 0.001*

Table 3: Median and Range of stereo-acuities (in arc seconds) obtained with the TNO and Titmus tests for each lens type. * Denotes statistical significance.

		ReZoom NXG	**AcrySof ReSTOR SN6AD1**	**AcrySof ReSTOR SN60D3**	**Tecnis ZMA00**	**Tecnis ZA9003**
	Lens Design	Refractive, Spherical	Hybrid, Aspheric	Hybrid, Spherical	Diffractive, Aspheric	Monofocal
TNO	*Median*	240	Figures	Figures†	480-Figures	60
	Range	60-none	60-none	120-none^	60-none	60-240
TITMUS	*Median*	55	60	50	50	40
	Range	40-400	40-200	40-140	40-200	40-80
	p	< 0.001*	< 0.001*	< 0.001*	< 0.001*	< 0.001*

(†) The Figures of TNO test have stereo-acuity values greater than 480 arc seconds

(^) The patient failed to manifest any measurable stereo-acuity with the TNO test

Table 4: Median and Range of stereo-acuities (in arc seconds) obtained with the TNO test with and without the +2.50 D lens. * Denotes statistical significance.

		ReZoom NXG	**AcrySof ReSTOR SN6AD1**	**AcrySof ReSTOR SN60D3**	**Tecnis ZMA00**
	Lens Design	Refractive, Spherical	Hybrid, Aspheric	Hybrid, Spherical	Diffractive, Aspheric
WITHOUT +2.50 D	*Median*	240	Figures	Figures[†]	480-Figures
	Range	60-none	60-none	120-none^	60-none
WITH + 2.50 D	*Median*	240	180	240	120
	Range	60-none	60-none	60-none	60-none
	p	0.378	< 0.001*	< 0.001*	0.001*

(†) The Figures of TNO test have stereo-acuity values greater than 480 arc seconds

(^) The patient failed to manifest any measurable stereo-acuity with the TNO test

FIGURES

Figure 1: Stereotests used in the study: (Top left) Titmus and (Bottom left) TNO. (Top right): double-polarized images of the Titmus test. (Bottom right): Red-Green disparity of the TNO test.

Figure 2: Spectral transmittances of the green and red filters used in the pair of glasses of the TNO test. (a) Filter transmittances (measured with spectrophotometry by the authors). (b) Product of each filter transmittance by the CIE luminous efficiency curve of the eye in photopic conditions.